

DIRECTED VISIBILITY ANALYSIS: THREE CASE STUDIES ON THE
RELATIONSHIP BETWEEN BUILDING LAYOUT, PERCEPTION AND
BEHAVIOR

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Yi Lu

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DIRECTED VISIBILITY ANALYSIS: THREE CASE STUDIES ON THE
RELATIONSHIP BETWEEN BUILDING LAYOUT, PERCEPTION AND
BEHAVIOR

Approved by:

Dr. John Peponis, Advisor
School of Architecture
Georgia Institute of Technology

Professor Michael Benedikt
School of Architecture
University of Texas at Austin

Dr. Craig Zimring
School of Architecture
Georgia Institute of Technology

Dr. Sophia Psarra
Bartlett School of Graduate Studies
University College London

Dr. Sonit Bafna
School of Architecture
Georgia Institute of Technology

Date Approved: March 20, 2011

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SUMMARY

This is a study of the spatial affordances of buildings that allow them to organize and transmit cultural ideas and to support the performance of organizational roles. The particular affordances under consideration are those that arise from the manner in which buildings structure the visual fields that are potentially available to a situated observer. Previous studies have shown that patterns of communication in offices, patterns of viewing and learning in exhibition spaces, patterns of everyday life in restrictive environments and patterns of wayfinding in hospitals are all systematically affected by the structure of visual fields. This study shows that the impact of spatial organization becomes clearer when we draw a distinction between generic visibility patterns and directed visibility patterns.

In studying generic visibility patterns we consider all parts of a setting that are visible from each occupiable location. In studying directed visibility patterns we focus on a previously specified set of visual targets and ask how many become visible from each occupiable location. Parametric restrictions concerning the direction into which a subject faces and the viewing angle sustained by the target object are also taken into consideration. The aim is to demonstrate how such refinements of visibility analysis, supported by the development of appropriate analytical tools, lead to more precise and penetrating insights as to how building users tune their behavior to the spatial affordances of environment, and how the environment impacts their understanding in turn. Three different studies were presented. All of them dealt with specific type of built environments in which the main task of the users is to attend visually to a fixed set of objects. The first used directed visibility measures to evaluate the affordances of different

nursing-unit designs relative to how well nurses are able to survey patients in different rooms as they go about their duties. The second study focuses on the manner in which nurses and physicians position themselves in a Neuro Intensive Care Unit (ICU), particularly when interacting. The third study investigates how aware exhibition visitors become of the visual structure of environment and how the visibility structure of exhibitions affects the ability of visitors to conceptually group paintings according to their thematic content.

The case studies reported in the thesis support the following conclusions.

1) The way in which people position themselves in an environment as they perform their assigned tasks is tuned to the way in which visual fields are structured. Thus, the pattern of space occupancy over time becomes a quantifiable material manifestation of role performance. This is as true in an ICU, where nurses and physicians perform differentiated tasks regarding the patients as it is in a virtual museum where visitors are asked to view exhibits. An important implication for spatial cognition follows: the visual structure of environment is cognitively registered in a natural way, as demonstrated by the quantifiable fine tuning of behaviors relative to them.

2) The visual structure of environment is contingent upon the interaction between the underlying structure of visual fields and paths of movement. Moving and seeing are correlated quite strongly. This become more evident in the virtual museum, where correlations between visual fields and visitors' responses to questions become much stronger when visual fields are analyzed taking into account the path walked rather than the setting as a whole.

3) Directed visibility analysis leads to stronger correlations with behavior and performance than generic visibility analysis. This implies that environments are layered. Their underlying spatial structure is charged by the distribution of the contents that are programmatically primary: paintings in a museum, patients in an ICU. By implication, the critical question that is highlighted by the thesis concerns the way in which the spatial allocation of programmatic elements charges an existing building layout. This is fundamental to the interplay between long term and short term building features, or, put more directly, the interplay between building architecture and interior architecture.

CHAPTER 1: INTRODUCTION

The literature of architecture and environmental psychology suggests that visual fields play an important role in the experience of buildings and patterns of space use (Benedikt, 1979; Frankl, 1973; Gibson, 1979). This resonates with the embodied cognition approach to psychology, which argues that cognitive processes and abstract concepts are deeply rooted in bodily interactions with the environment (Wilson, 2002). Thus, the way in which we perceive buildings as we move around them may not affect only our appreciation of architecture (Frankl 1973), but also our more fundamental cognitive interactions with the environment, architectural as well as social, organizational and cultural.

Recently, a growing body of empirical studies has established that the patterns of visibility towards selected objects or building components – as systematically analyzed and quantified - influence different kinds of cognitive processes and behaviors; some of these studies will be reviewed later. For example, the visibility of displays in museums affects visitor's movement, engagement and experience (Peponis, Dalton, Wineman, & Dalton, 2004; Psarra, 2009; Stavroulaki & Peponis, 2003; Tzortzi, 2004); the visibility of moving people from work stations in office affects interactions (Hillier & Penn, 1991; Markhede & Koch, 2007; Penn, Desyllas, & Vaughan, 1999; Peponis, et al., 2007); the visibility of building elements, landmarks or corridor intersections affects wayfinding behaviors (Braaksma & Cook, 1980; Churchill, Dada, Debarros, & Wirasinghe, 2008; Haq & Zimring, 2003; Lam, Tam, Wong, & Wirasinghe, 2003; Omer & Goldblatt, 2007).

This literature suggests that some objects have special significance in certain type of buildings in which the users visually attend to those objects, such as paintings in a gallery or patients in an intensive care unit. These are called “targets” in this dissertation. However, in most syntactic methods of visibility analysis in architecture, those targets receive no emphasis. In other words, all visible points are equally taken into account as potential destinations of lines of sight. Thus, one specific methodological contribution of this study is to propose a refinement of the standard analysis of visual fields. In essence, the refinement consists in drawing a distinction between general visibility, that is visibility equally extending in all available directions from each position in a setting, and directed visibility, that is visibility directed towards a set of pre-selected targets. Computationally, this has been developed both as a script on top of the most popular tool of 2D visibility analysis, DepthMap developed by Alasdair Turner at UCL, and as a standalone routine on a GIS platform, to accommodate subtler constraints, including distance radius, azimuth and angular size.

1.1 General hypothesis

Based upon this innovation in visibility analysis, this study examines the following hypothesis. The relationships between the spatial affordances of environment regarding visibility, the performance of organizational roles in work environments, and the understanding of displays in exhibition environments all become clearer when we draw a distinction between generic visibility patterns and directed visibility patterns.

Three different case studies are presented to test this hypothesis. The choice of case studies is guided by a desire to focus on settings where interactions and the co-

visibility patterns between habitual actors are of primary importance, and on settings where exposure and cognitive responses to visual information are the primary consideration.

1.2 Overview of the dissertation

The dissertation is organized as follows.

Chapter 2 provides a review of how theories about visual fields have evolved, how syntactic methods of visibility analysis have been gradually extended and how empirical research has developed to address a number of different questions.

Chapter 3 introduces the refined visibility analysis, which supports parameters including azimuth, radius and object's angular size. The refinement is based on the visibility directed towards a set of pre-selected targets.

Chapter 4 (case study 1) compares the degree of visibility toward patient beds among three nursing units using the refined visibility analysis. The assessment of three nursing units with the refined visibility analysis is tested against a previous empirical evaluation.

Chapter 5 (case study 2) tests whether people with different roles (nurses vs. physicians) are tuned to different visual features of environment in an intensive care unit.

Chapter 6 (case study 3a) investigates whether the visual information based on sensory-motor experience influences the perceived salience of displays in simulated 3D exhibitions.

Chapter 7 (case study 3b) investigates whether participants can consciously direct their attention to a pre-selected set of objects in simulated museum environments by

finding the locations that maximize the visibility towards those objects, rather than towards the open spaces.

Chapter 8 summarizes major findings, overall conclusions, and directions for future work.

CHAPTER 2: VISIBILITY ANALYSIS IN ARCHITECTURE

This chapter presents a review of syntactic methods of visibility analysis and empirical studies of the behavioral impacts of visual fields. The review focuses on the spatial structure of environments and the behavioral and perceptual affordances associated with it, not the specifically architectural qualities of buildings.

The first part of this chapter will discuss different analysis methods that focus on visual structure, including isovist fields, e-partition and s-partition, and visibility graph analysis. The different computational approaches and motivations of those analytic methods will also be discussed.

The last part of this chapter will describe empirical studies that link various visibility measures to behavioral outcomes in different settings.

Based upon the review, one specific methodological contribution of this study is to propose a refinement of the standard analysis of visual fields, to be explained in the following chapter.

2.1 Analysis of visual structure

In this section, different analysis methods that focus on visual structure, including isovist fields, e-partition and s-partition, and visibility graph analysis, will be introduced (see summary Table 2.1). These various approaches describe the visual structure of the built environment in such a way as to facilitate an understanding of its deeper cognitive

structure. The different computational approaches and motivation for those analytic methods will also be discussed in detail.

2.1.1 Benedikt's seminal work

The seminal concepts of visibility analysis are isovists and isovist fields (Figure 2.1: (a), (b)) which were introduced in the architectural literature by Benedikt (1979). An isovist is defined as “the set of all points visible from a given vantage point in space” (Benedikt, 1979, p. 49). Benedikt also proposed six geometric measures for isovists: area; perimeter; occlusivity (or length of occluding boundaries within the isovist); variance and skewness of the radial distances around each vantage point; and circularity, defined as the ratio of the square of the perimeter to area. To show how certain properties of isovists change across space, he also introduced the concept of the isovist field, which represents the change in a given measure of an isovist in all locations of a layout by using contour lines. The author suggests that isovists and isovist fields are related to Gibson’s model of visual perception because they capture the variation of visual fields that informs the spatial understanding of people in motion (Gibson, 1979). Isovist fields are used to capture the variance of certain visual information across different locations. When the contour lines in isovist fields are packed together more tightly, the visual information in those areas changes more rapidly. When the contour lines are more separated, the visual information in those areas is relatively stable. Benedikt and Burnham further explored the effect of the properties of isovists on perception, finding that perceived 'spaciousness' was related to the complexity of the isovist rather than to the area of the isovist (Benedikt & Burnham, 1985).

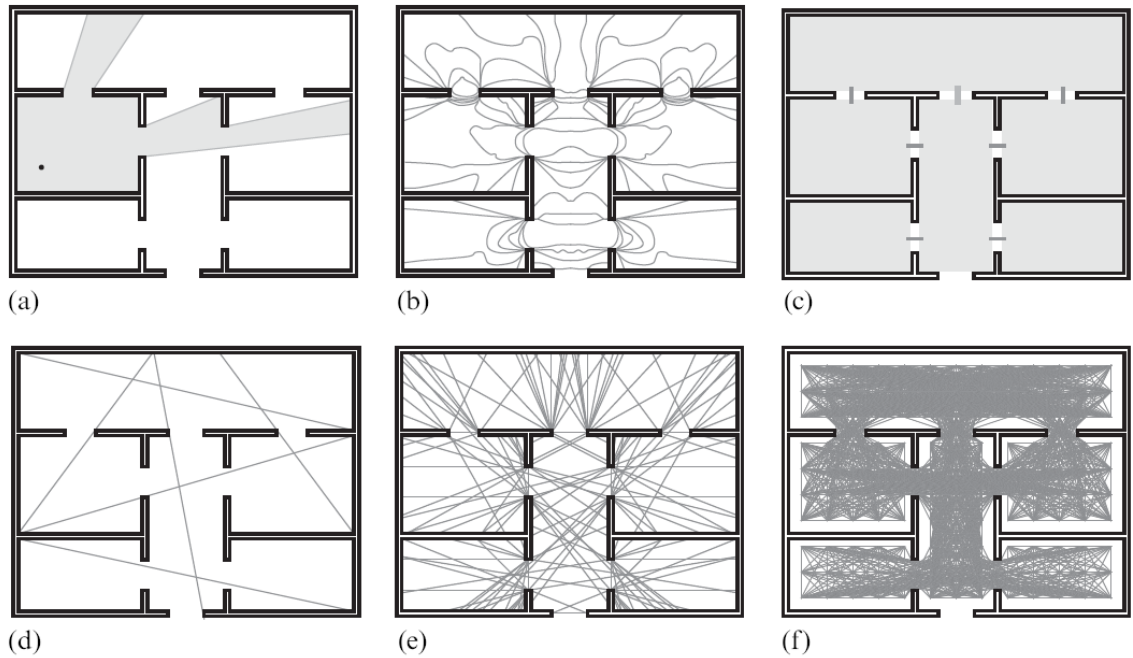


Figure 2.1: Existing visibility analysis methods.

(a) An isovist polygon is a two-dimensional slice through the volume visible from a location. (b) An isovist field of isovist area provides contour lines of equal visible area. (c) The set of convex spaces for a configuration. (d) A set of axial lines. (e) The e-partitions produce areas where the number of visible surface edges does not change. (f) A dense grid visibility graph records the connections between mutually visible locations, which may then be used for graph analysis. Source: (Turner, 2003).

Table 2.1: A comparative table of various visibility analysis approaches.

methods	Author	Computation method	Measures	software
Isovist	Benedikt (1979)	Construct visibility polygon	Area, perimeter, occlusivity (or length of occluding boundaries within the isovist), variance and skewness, and circularity	NA
Isovist field	Benedikt (1979)	Construct contour lines of equal visual area	The compactness or sparseness of contour lines.	NA
e-partition s-partition	Peponis et al. (1997)	Construct alternative partitions that capture some properties of visibility polygon	defining 'informationally stable' units with respect to form, by considering the visibility of discontinuities of shape, such as corners and edges of wall surfaces.	Spatialist
Isovist computation	Batty (2001)	Infer visibility polygons from an analysis of regularly tessellated space	Similar isovist measures as Benedikt's	starlog
Visibility graph analysis	Turner et al. (2001)	Construct graph of inter-visible points. Each edge represents a visible connection between them.	Local properties: Neighborhood size, clustering coefficient Global properties: Mean shortest path length, visual integration	Depthmap

2.1.2 Space syntax theory

Hillier and his colleagues have developed a set of theories and techniques, known as "space syntax", in order to measure the properties of built space that are involved in its generic social, behavioral and cognitive functions (Hillier & Hanson, 1984). The basic units of description of space syntax- the convex map, and the axial map-are closely related to the isovist and sight line (Figure 2.1: (c), (d)). But in space syntax, attention is directed to the fundamental relational properties between spaces rather than to the geometry and metric properties of shape. Once plans are expressed in the form of either a convex map or an axial map, space syntax uses graph-theoretic techniques to compute

how one element is connected to the other elements of the map. More recently, the visual field available from an axial line or from a convex spatial unit has been used to enhance the description of the configuration of plans in the literature. For example, Hanson applies isovists as well as space-syntax techniques to 'deconstruct' several well-known architects' houses (Hanson, 1994). She examines the way architects have composed space, much as Benedikt looks at representative values of isovist fields for different styles of architecture. However, in early space syntax, as represented in the seminal book *The Social Logic of Space* by Hillier and Hanson (1984), the analyses of convex patterns of accessibility, axial patterns of movement, and visual fields were not explicitly integrated into a single framework.

2.1.3 Peponis's visual information about edges, corners, and surfaces

At Georgia Tech, Peponis and his colleagues developed an alternative approach to construct partitions of otherwise continuously linked built space that are sensitive to the way in which the surrounding built shape is perceived by an observer situated inside a building (Peponis, Wineman, Rashid, Kim, & Bafna, 1997). The method is based on the appearance or disappearance of visual information about edges, corners, and surfaces (Figure 2.1: (e)). This method relies on a specific way of partitioning a given floor layout into a stable and unambiguous set of convex spaces. The most elaborate of such partitions is the end-point partition (e-partition), which is obtained by extending the visibility diagonals that link edges and corners without crossing a wall, in addition to extending all extendable surfaces. The end-point partition captures the variation of occluding edges as a situated observer moves inside a building (Peponis, et al., 1997). Such occluding edges

are crucial to the acquisition of three-dimensional information about a layout (Gibson, 1979). Thus, the authors suggest that the end-point partition is important to understanding the shape of an environment.

Another proposed partition, the surface partition (s-partition) arises from extending all extendible surfaces to construct convex spaces at the boundaries of which a complete wall surface either comes into or disappears out of the field of vision. The s-partition is considerably less complicated than the e-partition.

The larger argument based on the construction of the e-partition and the s-partition is that all higher order spatial units of interest to space syntax can be derived from the analysis of fundamental relationships between boundary surfaces and edges. In this way the Georgia Tech team has sought to provide an integrated geometric foundation to space syntax, bringing together modes of analysis that had previously been distinct: lines or axial analysis and convex analysis in the original space syntax theory, and isovist analysis introduced into space syntax from the work of Benedikt. The authors also developed software, Spatialist, to automatically create e-partitions and s-partitions for a given layout, as an extension on Microstation 95, a CAD package from Bentley Inc.

2.1.4 Batty's computational methods for isovist

Following up on Benedikt's idea, many studies developed various measures and computational methods for isovists to capture the effects of visual structure. Batty (2001) offers a computational scheme for defining isovists and measuring the properties of isovists by tessellating space into a regular grid in which each grid unit is associated with a centroid point. He demonstrates that it is possible to compute isovist fields, to display them in standard ways, and to develop basic statistical measures which detect explicable

variations in architectural and urban morphology. He revisits Benedikt's isovist attributes such as area, perimeter, occlusivity, variance and skewness of radial distances around each vantage points, and circularity, by analyzing the set of visual grid centroids from a vantage point.

2.1.5 Visibility graph analysis

At the same time, Turner and his colleagues (2001) used the visibility graph between of a grid of points in order to compute measures of visual connectivity as well as measures equivalent to the isovist, without actually explicitly generating isovist polygons.

What is more important, the researchers combined the theory of space syntax (Hillier & Hanson, 1984), small worlds analysis (Watts & Strogatz, 1998) and isovists into their measures. Through the integration of those methods, certain local and global spatial properties could be quantified.

1) Neighborhood size (or visual connectivity) of a node is the set of nodes immediately connected through an edge in the node graph. Conceptually, it represents the set of points that is visible from a location, which can be thought of as equivalent to the area of an isovist. Neighborhood size is local property, for the spatial information is immediately available from the location of interest.

2) Clustering coefficient is defined by the ratio of number of edges between all nodes in the neighborhood of a node and the total number of possible edges within that neighborhood of that node. The authors believe that clustering coefficient gives a “measure of proportion of inter-visible space within the visibility neighborhood of a

point”(Turner, et al., 2001). It can also indicate how much visual information will be changed when moving away from a location.

3) Mean shortest path length (or mean depth) represents the average number of the fewest visual steps that need to be traversed to get from a location to every other point. "Visual step" is a crucial concept in the node graph of visibility. It indicates the visual relationship among points. If two points are mutually visible, then they have a direct visual relationship. On the other hand, two points can be mediated by various visual steps, depending on how many intermediate points are needed to visually connect the pair.

The algorithm for mean shortest path length of node i can be expressed as

$$MD_i = \frac{\sum_{j=1}^n depth_{ij}}{n-1}$$

Where $depth_{ij}$ is the fewest visual steps between node i and node j, n is the total number of nodes in the system. The notion is directly borrowed from Space Syntax theory (Hillier & Hanson, 1984). It captures the degree of the accessibility of a location to the rest of the system. The visual integration is essentially a normalized value of mean shortest path length to make different systems comparable.

What is more important, the first author, Alasdair Turner, developed a software called Depthmap to calculate various measures of visual fields, which has become one of the foundations for the growth of the entire research field.

2.1.6 Summary

The work reviewed above is of interest because it moves from the traditional description of particular views (in perspective drawings), to a description of visual structure, that is the pattern of relationships between views and the underlying properties of the visual fields that are available to a situated or moving observer.

As shown in this section, different researchers use different computational approaches. Some directly construct visibility polygons (Benedikt, 1979), some construct alternative partitions that capture some properties of visibility polygons (Peponis, et al., 1997), some infer visibility polygons by tessellating space into a regular grid in which each tile is associated with a centroid point (Batty, 2001), and some construct visibility graphs (Turner, et al., 2001) where each node in the graph represents a point location, and each edge represents a visible connection between points.

The following section will focus on the empirical studies that link various visibility measures and behavioral outcomes in different settings. Furthermore, the limitations of current visibility measures will also be identified.

2.2 Behavioral Impacts of Visual fields

Despite the advance in the methodology and its close relationship to visual perception, the application of visibility analysis is limited to a small number of studies, most of which focus on exhibition settings. Furthermore, many researchers have invented various non-standard visibility measures to promote their research aims.

2.2.1 Museums and exhibitions

Many studies have found that the structure of visual fields is especially important in museums. Curators frame visibility in order to 1) transmit subtle messages about exhibitions; 2) Shape visitor's movement and co-presence, 3) influence overall experience. 4) Potentially influence learning outcomes. Examples of each of these are outlined below.

1) A substantial literature exists on how curators may realize their intentions through the layout of objects within space (Staniszewski, 1998). More particularly, co-visibility among objects articulates the ideas and relations between objects and groups, with shared formal characteristics, functions, and choice of materials (Staniszewski, 1998).

This exhibition technique can be traced back to the innovative exhibition installation of 'Arts of the South Seas' by D'Harnoncourt, Ralph Linton and Paul Wingret at Museum of Modern Art, New York in 1946 (Staniszewski, 1998). The exhibition was structured as network of atmospheric galleries whose wide entrances, wall partitions, and display structures permitted the viewer to compare and harmonize the contents of one area or gallery with that of another (Figure 2.2)(Staniszewski, 1998, p. 111). The curatorial intention is to show the relations between many displays from different cultures through the co-visibility among displays in different galleries. For example, in the Solomon Islands galleries, the viewer could look past a waist-high wall partition studded with artifacts in to the Polynesia gallery and past this to the Easter Island section (Staniszewski, 1998, p. 111).

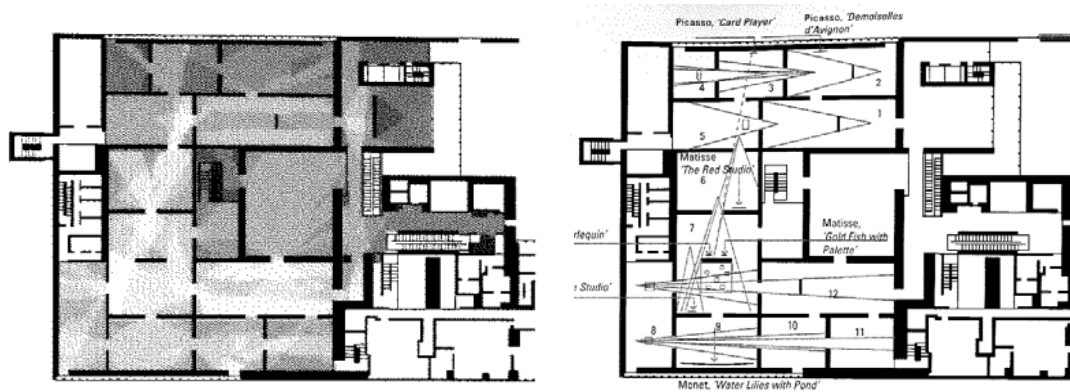


Figure 2.3: Visibility analysis of MoMA.

Left: Visual integration (a normalized form of mean depth) was created in Depthmap in Psarra's study. Right: the co-visibility among paintings was manually constructed in the same study. Source: (Psarra, 2009)

2) Shaping movement and co-presence. The structure of visual fields not only reflects and expresses pedagogical goals, but also shapes patterns of movement and co-presence in a layout. Empirical studies show that the pattern of spatial integration in a spatial layout will correlate to a significant degree with the pattern of movement (Hillier & Tzortzi, 2006). For example, Choi investigated how far movement in the spaces of eight art museums in the US was shaped by spatial layout (Choi, 1999). He recorded visitors' itineraries and spatial distribution within the layout in two ways: first as "state" counts by recording the numbers of people, both static and moving; second, as "dynamic" patterns, by unobtrusively tracking individual itineraries and recording the frequency with which each space was visited. The results show that for the "state" description there was only an inconsistent relation between the occupancy of an individual space and configurational variables. For people that could be seen from each space, there was, however, a strong and consistent relation with configurational variables. The author distinguishes two models of the effect of museum layouts. The deterministic model

dictates view sequences and encounters by offering few circulation alternatives. The probabilistic model modulates exploration and encounters statistically according to the syntactic properties of the layouts, while providing multiple circulation alternatives.

Similarly, Hillier & Tzortzi (2006) report that the average density of movement traces of 100 Tate gallery visitors in each space was highly correlated with the average visual integration value (i.e. the standardized mean depth) of all points in that space ($r^2=.68$), indicating that 68 percent of the variance in movement density between spaces was related to the pattern of visual integration in the layout. The authors argue that the structure of visual fields shapes a certain pattern of co-presence amongst visitors.

3) Most recently, several studies show that co-visibility among displays influences overall experience. For example, Stavroulaki and Peponis found that the location and facing of sculptures forms spatial narratives in the Castelveccchio museum by Scarpa (Stavroulaki & Peponis, 2003). The authors argue that the location of each statue took into account that of others, so that their gazes are either directed toward each other, or intersected at a common point in space. More interestingly, the authors make a distinction between continuously changing visual fields of space and discontinuous changing visual relationships of the gazes of statues. In the case of this museum, the exploration of sculpture galleries does not provide only a view of displays but also a reflexive experience of space as a field of co-presence (Stavroulaki & Peponis, 2003).



Figure 2.4: The visibility analysis of Castelvecchio museum. The discontinuous changing visual relationships of gaze of statues provide a reflexive experience in the Castelvecchio museum by Scarpa. Source: (Stavroulaki & Peponis, 2003).

More recently, Stavroulaki and Peponis enriched visibility analysis of icons in churches and museums by taking into consideration co-visibility of icons and paintings with orientation and angle restrictions. The authors draw distinctions between potential co-visibility and comparative co-visibility in relation to an object—in this case an icon. Potential co-visibility is associated with lying on the edge of the same visibility polygon. Comparative co-visibility arises when icons in addition to the reference icon become distinctly visible within the cone of vision, or the horizon of a visibility polygon, taking into account the distribution of light. The authors develop visibility analysis by correlating the geometry of visual fields and the relationships of visual connectivity to the distribution of light.

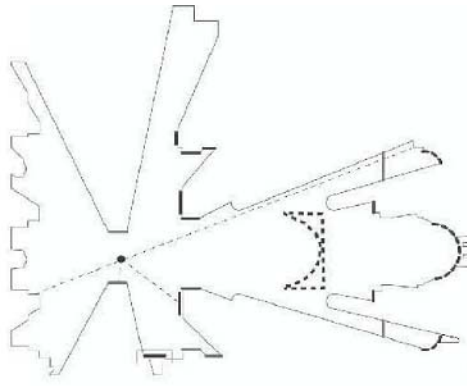


Figure 2.5: the co-visibility of icons and wall paintings.
The 60 degree cone of vision that encompasses the icon and 180 degree horizon of view are indicated with dotted lines. Source: (Stavroulaki & Peponis, 2005)

4) The visibility structure also potentially influences visitors' learning outcomes. Peponis and his colleagues investigated the effect of co-visibility of individual exhibits on visitor's behavior in open plan science exhibitions (Peponis, et al., 2004). They found that the contact score (i.e., demonstrated visitor awareness of exhibits indicated by proximity of visitor paths) of individual free-standing exhibits was associated with their visual accessibility (i.e. the generic visual connectivity and mean depth). The active engagement (i.e. recorded interaction between visitors and exhibits) was associated with co-visibility of individual exhibits, which represents the number of exhibits that a visitor can directly see, fully or partially from a given exhibits. The authors also reported that while sequencing of contacts was affected by the extent to which the plans were thematically grouped, engagements resulted from a conscious decision, the cognitive registration of thematic labels. The indirect behavioral evidence implies that the design of layout can add relationships between objects and affect the ways in which displays are perceived and cognitively mapped.

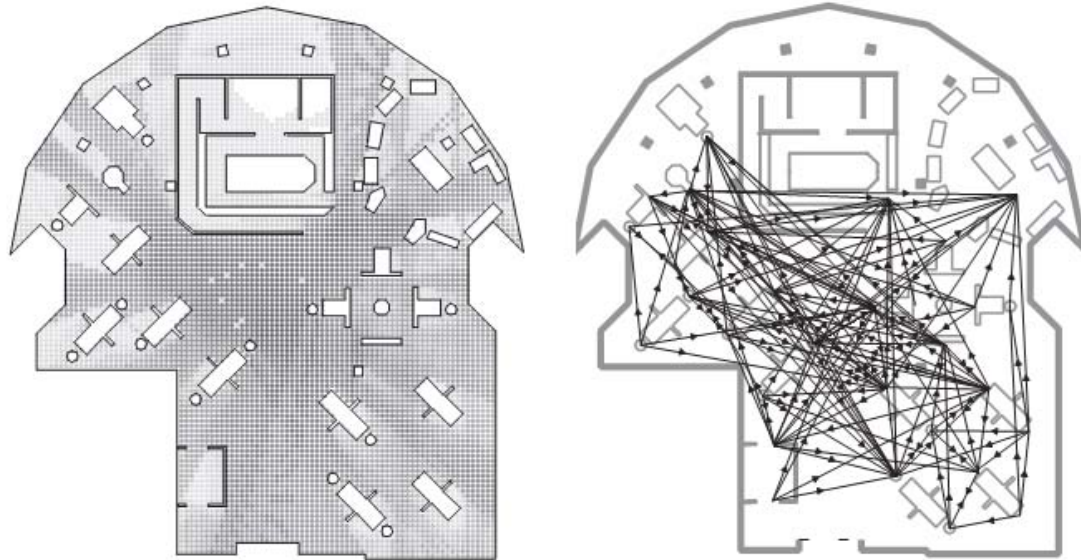


Figure 2.6: The visibility analysis of open plan science exhibitions.
 Left: the mean depth of each grid node in the layout. Right: the cross-visibility of individual exhibits that was manually constructed by the authors. Source: (Peponis, et al., 2004)

2.2.2 Restrictive environments

Peatross used the properties of visual fields to explore the spatial dimensions of control in restrictive environments as exemplified by three Alzheimer's units and three juvenile detention centers (Peatross, 2001). More importantly, a critical property developed in her study was the “populated isovist” that is the recoding of other people's presence over time in the isovist which is available to an inmate from a frequently occupied position. A space is considered more ‘animated’ when its isovist includes more moving than static people. Peatross argued that “animated isovists” helped to “normalize” everyday life in settings where inmates are otherwise subject to high levels of institutional control over behavior.

2.2.3 Offices

The visual fields are believed to have a strong impact on the interactions in office settings.

For example, Penn and his colleagues reported that patterns of space use and movement generated by spatial configuration and visual field have a direct impact on the frequency of contact between the workers of two companies in UK (Penn, et al., 1999). Since a person sitting at their workstation could never tell when a particular individual would walk past, the authors believe that the contact opportunities can be attributed to the effect of larger scale configuration and local visibility in bringing moving, and potentially ‘available’, people into the field of view of those at the workstation.

Peponis and his colleagues compare the visibility characteristics of the new and old office settings for the same organization by analyzing visual connectivity and visual integration (Peponis, et al., 2007). The workspaces in the new premises were visually more integrated and egalitarian than those in the old. These properties generated “intensified awareness and cognitive opportunity” in the new office.

Markhede and Koch (2007) argued that analyzing a selection of organized positions integrates social structures into the visibility analysis. The face-to-face interaction in offices was strongly correlated with the co-visibility measures among selected positions. The co-visibility graphs were produced by stand-alone software named Spatial Positioning Tool written by the author, though no quantitative measures were produced by the software.

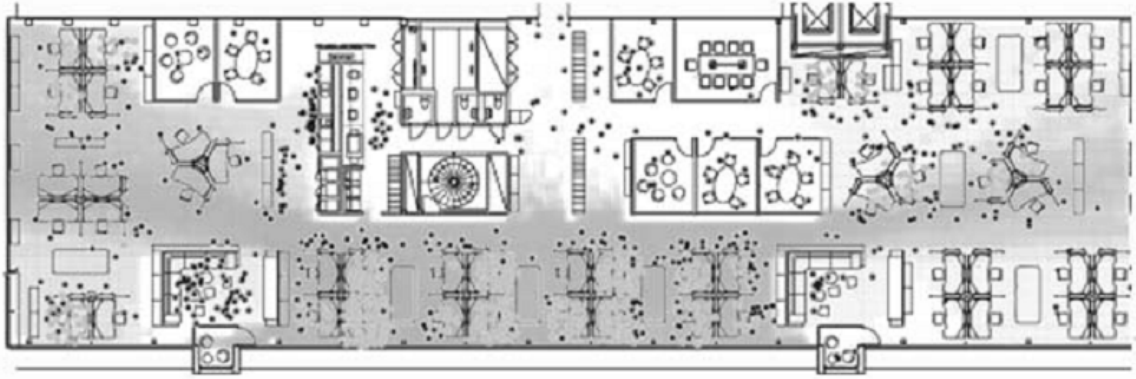


Figure 2.7: the relationship between face-to-face interaction and co-visibility for positions of workstations in the office. Source: (Markhede & Koch, 2007)

2.2.4 Wayfinding

Empirical studies support that visibility towards salient components in the environment can influence wayfinding performances and open exploration patterns.

Braaksma and Cook (1980) developed a quantitative measure to evaluate the ease of wayfinding in airport terminals. The measure is based on the matrix of visual accessibility between locations (Table 2.2). The visibility index is a global measure which represents the ratio of the number of available sight lines and the total number of possible sight lines. A relationship was found between the visibility index and self-reported difficulty in wayfinding in 10 airports. Locations with low visibility from other locations were reported as more difficult to find than those with high visibility.

Table 2.2: A part of the matrix of visual connectivity between locations in airport terminals. Source: (Lam, et al., 2003)

No.	locations	a	b	c	d	e	f	g	h
a	Entrance		1	0	0	1	1	0	0
b	Check-in	1		1	0	1	1	0	0
c	Departure gate	0	1		1	0	0	0	0
d	Boarding gate	0	0	1		0	0	1	1
e	Lifts	1	1	0	0		1	1	1
f	Elevators	1	1	0	0	1		0	1
g	Conveyer belt	0	0	0	1	1	0		1
h	Automated people mover	0	0	0	1	1	1	1	

Several follow-up studies further fine-tuned the visibility index measure for airport settings (Churchill, et al., 2008; Lam, et al., 2003). They proposed a modified visibility index, which is the ratio of the number of available sight lines and the total number of sight lines that should exist within the airport between related units. The authors argued that not all units are related to each other and may need to be accessed in sequence. Therefore, only the relevant sight lines within the network were considered.

Haq and Zimring also reported that during open exploration, people rely heavily on the number of visible decision nodes (i.e., how many additional nodal corridor intersections could be seen from a given node) by studying the movement paths of 128 participants in three large hospitals (Haq & Zimring, 2003).

Most recently, by studying the wayfinding performances of 14 people in a simulated virtual town, Omer and Goldblatt (2007) find a high degree of overlapping between the visual fields of an origin and a target landmark, which are measured by the number of common visible landmarks, improves wayfinding performance.

2.3 Closing remark

This chapter began with a review of a number of approaches to the analysis of the visual structure of a built environment. It has subsequently reviewed research showing how visual structure affects the behavioral, organizational and cognitive performance of buildings relative to their program of use.

The main approaches which make the visual structure measurable and tangible, are isovist fields, e-partitions, and visibility graph analysis. Each is associated with particular measures and is supported by particular computational methods. The most widely used software tool functions both as a pedagogical tool and as a research tool and was developed by Turner and his colleagues at the University College of London (Turner, et al., 2001). A visibility graph can be constructed by the software, where each node in the graph represents a point location and each edge represents a visible connection between them. This stand-alone software, Depthmap, can produce the following standard visibility measures: neighborhood size (visual connectivity), clustering coefficient, mean shortest path length (mean depth), and visual integration. Furthermore, Depthmap also has an associated scripting language, and is thus open for elaboration and development.

In the following chapter, I will propose a refinement of previous methods of analysis of visual structure, taking the material reviewed in this chapter as a point of departure.

CHAPTER 3: REFINED VISIBILITY ANALYSIS

3.1 The limitation of standard visibility analysis

The review in the previous chapter has shown how theories have progressively evolved, how syntactic approaches of visibility analysis have been gradually extended and how empirical evidence has been increasingly accumulated. Based upon the review, new questions are now open to investigation.

As demonstrated in the previous chapter, many researchers have tried to link various visibility measures and behavioral outcomes in different settings. Some researchers created non-standard visibility measures to enhance the application the visual structure, in addition to standard visibility measures, such as visual connectivity, visual mean depth or integration (Table 3.1). Sometimes concepts brought to bear on the analysis were of limited generalizability as stated, or difficult to render in computable terms. At other times, direct and generalizable computational implications could be discerned: for example the requirement to analyze what can be seen when facing in a particular direction is both general and open to computational interpretation. The requirement to analyze patterns of co-visibility implies thresholds of distance for sufficiently distinct viewing which may be context-dependent. The purpose of this chapter is to identify some of the suggestions for visibility analysis that are more generalizable, as a foundation for the technical contribution of this thesis.

Table 3.1: visibility measures that were used in various empirical studies (see detailed review in previous chapter).

Setting	Author	Standard visibility measure	Non-standard visibility measure
Museum	Psarra (2009)	Visibility integration	Co-visibility for paintings
Museum	Hillier & Tzortzi (2006)	Visibility integration	NA
Museum	Stavroulaki & Peponis (2003)	NA	Co-visibility between individual statues with azimuth restriction
Museum	Stavroulaki & Peponis (2005)		Co-visibility between individual icon with azimuth and distance restriction
Museum and exhibition	Peponis et al (2004)	visibility connectivity, mean depth	Co-visibility between individual exhibits with azimuth restriction
Restricted environment	Peatross (2001)	NA	Animated isovist- the ratio of moving people to static people
Office	Peponis et al (2007)	Visibility integration, visibility connectivity	NA
Office	Markhede & Koch (2007)	NA	Co-visibility graph from selected positions of workstations.
Wayfinding	Braaksma & Cook (1980)	NA	Co-visibility between locations
Wayfinding	Haq & Zimring (2003)	NA	number of visible decision nodes, i.e., how many additional nodal corridor intersections could be seen from a given node
Wayfinding	Omer et al (2007)	NA	Co-visibility between landmarks

First of all, many empirical studies demonstrate the importance of visibility towards specific objects or locations. For example, visibility towards display objects in museums affects visitor's experience; visibility to moving people from work stations in offices affects interactions, and visibility towards other building components, landmarks or corridor intersections influences wayfinding behaviors. Researchers for many such

studies have had to manually perform specialized tasks of visibility analysis or create the visibility graph due to the lack of proper tools in the fields.

Furthermore, some studies found that impact of visual structure becomes clearer when certain restrictions are applied. For example, Stavroulaki & Peponis (2003) reported that the location and facing direction of sculptures form spatial narratives in the Castelvechio museum. Thus, they construct the overlapping limited viewsheds of approximate 30 degree of field of view while considering the orientation of each sculpture. Similarly, Stavroulaki & Peponis (2005) also utilized two angles of views: a 60-degree cone of vision that encompassed the icons under study, and 180-degree horizon of view when the icon is at the focus of attention. They also proposed three kinds of radials at varying distances: near, far and interim.

Peponis and his colleagues (2004) reported that the recorded interaction between visitors and exhibits was associated with co-visibility of individual exhibits, which represents the number of exhibits that can directly see a particular exhibits, fully or partially. The co-visibility was empirically established with consideration of the orientation of people engaging the exhibits.

In most syntactic methods of visibility analysis, all occupiable and visible points of a setting are equally taken into account as potential origins and destinations of lines of sight. It is also impossible to specify the orientation and angle restriction of the visual fields in the standard software, such as Depthmap.

This study addresses those gaps. One specific methodological contribution of this study is to propose a refinement of standard analysis of visual fields. In essence, the refinement consists in drawing a distinction between general visibility, that is visibility

equally extending in all available directions from each position in a setting, and directed visibility, that is visibility directed towards a set of pre-selected targets (Figure 3.1). However, as will be shown in subsequent sections, this major refinement leads to other refinements.

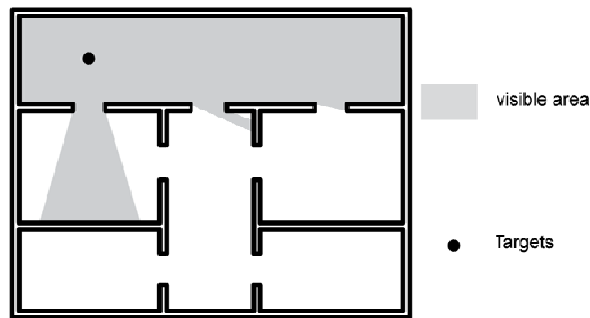


Figure 3.1: The proposed visibility analysis.

It consists in visibility directed towards a set of pre-selected targets (i.e., all-to-targets relationship). It is a refinement of standard visibility analysis, which consists in visibility to and from all open spaces (i.e., all-to-all relationship).

3.2 The Conceptual Approach

The conceptual development of directed visibility is grounded in Gibson's theory of visual perception, mainly his argument of affordances. For Gibson, the relationship between species of animals and the environment is defined reciprocally through affordances, which are what the environment offers, provides, or furnishes for either good or ill (Gibson, 1979, p. 127). They are the functionally significant properties of the environment with regard to a particular animal. A simple example can clarify the

characteristics of affordances. A 1-meter-high wall can afford seating for a 1.7-meter-tall adult, but not for a half-meter-tall child. Therefore, the affordance of seating is determined both by the environment and the individual of interest. The concept of affordance “cuts across the dichotomy of subjective-objective” (Gibson, 1979, p. 129). In other words, affordance is objective because it refers to environmental properties, but it is also subjective because it is related to a particular individual. Gibson further suggests that the information about affordances that an environment provides can be picked up directly: “The perceiving of an affordance is not a process of perceiving a value-free physical object to which meaning is somehow added...it is a process of perceiving a value-rich ecological object.... Physics may be value-free, but ecology is not” (Gibson, 1979, p. 140). Therefore, the functional significance of environments may be perceived directly.

Even though, Gibson discussed affordances related to species of animals, there are invariants that enable two or more people with same roles or same demographical categories to perceive the common affordance simultaneously: for example, the affordance of the stethoscope for physicians, or the affordance of the toy for children.

In summary, Gibson’s suggestions are two-fold. First, for different sets of people (e.g. people with same role or demographic background), certain environmental properties are functionally more significant than others, and those properties can be directly perceived. Consequently, the visibility analysis should focus on certain visual features of an environment that are most relevant to its habitual users. The visual structure of these functionally significant elements could facilitate an understanding of how people perceive and behave. Second, different sets of environmental elements may

be functionally significant for different groups. Thus, a visibility analysis should focus on different sets of visual features in an environment that are closely related to different sets of users.

3.3 Directed visibility analysis

As we discussed above, there are some critical objects or locations which can have great behavioral or cognitive impacts on people in architectural spaces. However, the generic visibility analysis is based on all visible locations, rather than selected critical locations. Our measures want to address the gap, by performing visibility analysis related to the locations of specific objects.

Initially, we developed the directed visibility analysis as a script in Depthmap software. The added script calculates how many pre-selected targets are visible from each location. Later, we developed and customized on the ArcGIS version 9.2 platform (ESRI Inc., Redlands, CA) with component object model-based ArcObjects and Visual Basic for Application language (Microsoft). The ArcGIS platform is more flexible to implement various restrictions for visibility analysis.

Directed visibility is applicable to standard floor layouts, that is, those that are largely horizontal, planar, and partitioned or articulated by mostly vertical walls or furniture. To run the directed visibility analysis, a user must input the following data: the floor plan; the set of preselected targets; the cell size of a grid of observation points; and optional restrictions including azimuth, distance radius, angular size.

The GIS computation works in this way. First, a uniform grid of observation points is superimposed on the top layer of a floor plan. Then, a unique identity value is

automatically assigned to each specific visual target, which is represented by either a point or an area in GIS. After that, a straight line representing a line of sight is constructed toward each target from an observation point. If the straight line does not intersect with the lines in the floor plan, the target is counted as visible at screening stage. Otherwise, the target is treated as invisible at screening stage. Then, each visible target obtained at the screen stage is checked against various restrictions, such as distance radius, or azimuth. At last, for each observation point, the number of visible targets is tallied and entered into a table.

One thing should be clarified. One target is treated as visible whether it is partially or fully visible. This is not a fundamental handicap but an operational convenience. Targets can be redefined in more limited ways if specific parts of them are more important.

3.4 Directed visibility Index

To compare the degree of directed visibility among different buildings, the directed visibility index (DVI) is introduced here. It is based on the comprehensive collection of directed visibility data from all occupiable locations. It is defined as the ratio of the average directed visibility value of all locations in the setting to the number of preselected targets. Thus, the directed visibility index measures the degree to which an observer can see all targets in a setting.

3.5 Restrictions of Azimuth, Radius and Object's angular size

Another specific methodological contribution is to implement restrictions to standard analysis of visual fields. In essence, the restrictions include azimuth, radius and object's angular size (Figure 3.2).

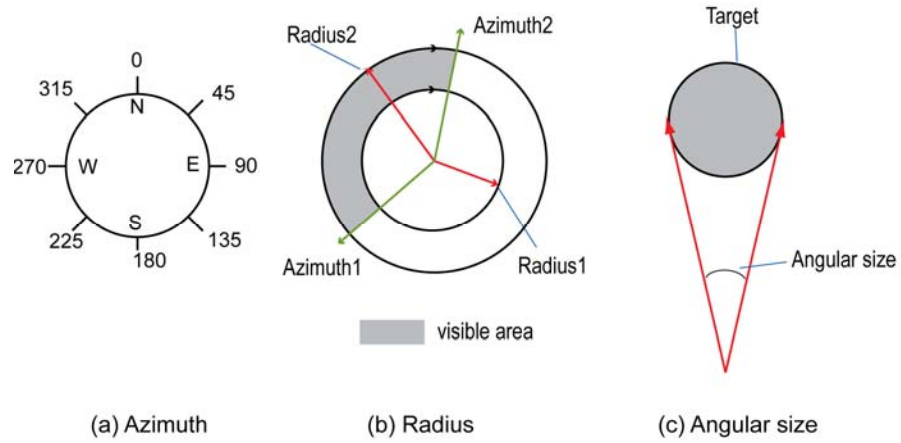


Figure 3.2: The restrictions implemented in the visibility analysis.
 (a) Azimuth specifies horizontal angle limits. (b) Radius limits the search distance. (c) Angular size limits the horizontal apparent size of an object.

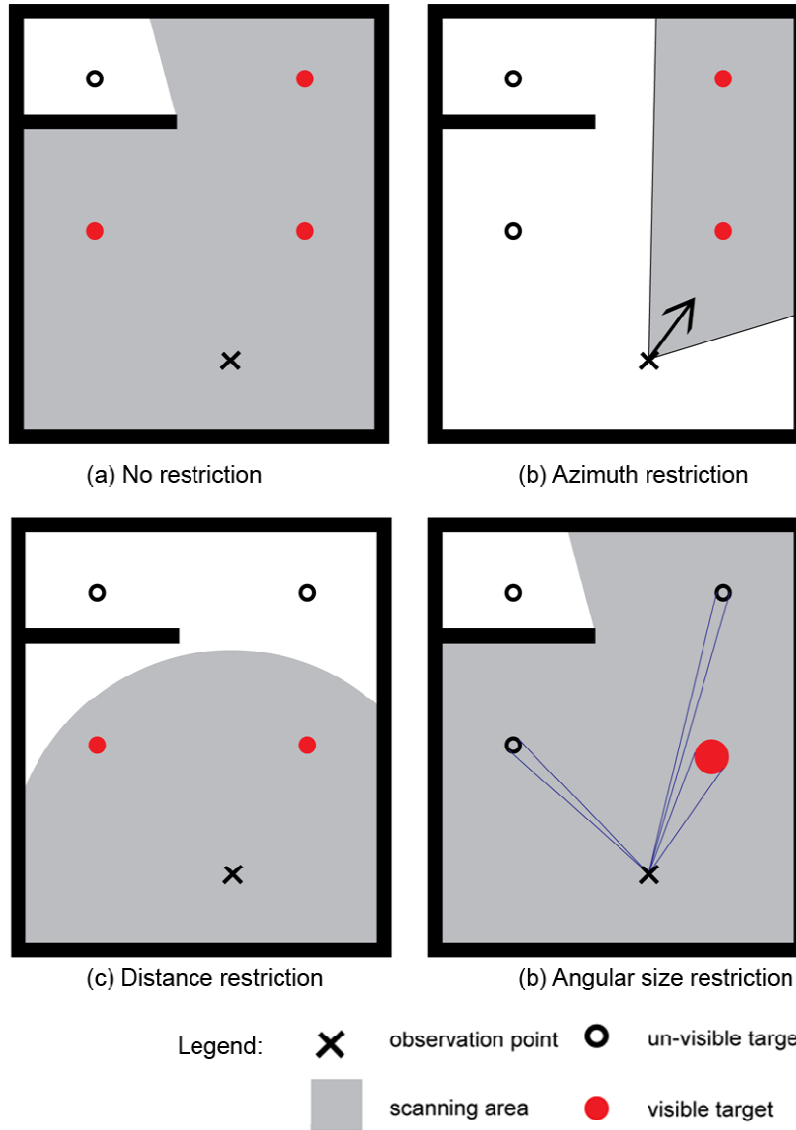


Figure 3.3: The examples of directed visibility analysis with the various restrictions.

1) Azimuth specifies horizontal angle limits when identifying targets visible from each observation points (Figure 3.2 (a), Figure 3.3). It is implemented because humans do not have a full 360-degree view fields. The actual azimuth is related to the orientation of people and the angle of view fields. Users can specify two Azimuth values as the range of

the permitted visual fields. The default values are 0 and 360 respectively, which would implement a full 360-degree sweep.

With the azimuth restrictions, it is possible to apply visual analysis to moving people, if we know the location, orientation (O in degree) and field of view (F in degree) for the people at each time. The two azimuth values should be $O-F/2$, $O+F/2$. However, in real life, the orientation and field of view are difficult to record because both of them are dynamic during movement. Hence, in one of my case studies (Chapter 6 & 7), the simulated 3D environment was used as the setting. The field of view is fixed at 100 degrees throughout the experiment. The orientation and location of participants was recorded a time interval of .05 second. Thus, we can analyze the visual fields of the moving participants with accuracy. As shown Chapter 7, this refined visibility analysis proved more powerful in predicting cognitive outcomes.

2) Radius limits the search distance when identifying targets visible from each observation point (Figure 3.2 (b), Figure 3.3). Again, users can specify two radius distances as the range of search distance (radius1 and radius2; radius1 should be smaller than radius2). Any targets beyond the radius2 search distance or closer than radius1 search distance are excluded from the analysis. The default radius1 distance is zero, and the default radius2 distance is infinity.

According to Edward Hall's theory of proxemics (1966), the quality of visual awareness is believed to be a function of distance. He categorizes distance as (1) intimate space (0 to 18 inches), where vision is distorted and body heat and smell are perceived;(2) personal space (18 inches to 4 feet), where eyesight begins to focus, and a sense of body heat is barely noticeable;(3) social space (4 feet to 10 feet), where the eye

can focus on an entire face, and one must rely solely on what can be seen and heard; and (4) public space (10 feet to infinity), where the eye can take in the whole body at a glance, and subtle nuances of meaning from the face are not available (Hall, 1966). Hall's classification of distance may not be applied directly to other studies; nevertheless, it is proposed that a combination of directed visibility and different distance radius could be used to identify the thresholds that apply for various kinds of relevant awareness (recognizing faces, examining paintings etc). Setting a radius provides the possibility of analyzing large scale environments more realistically from the point of view of directed visibility. It should be noted that it is also possible to specify a distance radius restriction in Depthmap.

3) Object's angular size is the horizontal angle a viewed object subtends at the eye (Figure 3.2 (c), Figure 3.3). It limits the apparent size of an object when identifying visible targets in the analysis. The angular size combines both the distance to an object and the actual size of it. For two round objects of the same size, the angular size of the closer objects is larger than that of the other. For two round objects of different sizes placed at same distance to an observer, the angular size of the large objects is larger than that of the other. Users can specify one angular size. Any targets are smaller than the angular size are excluded from the analysis. The default angular size is zero.

3.6 Closing remarks

In this section, two major limitations of standard visibility analysis were identified through reviewing previous studies. First, many empirical studies demonstrate that the importance of visibility towards specific objects or locations. For example, visibility

towards display objects in museums affects visitor's experience; visibility to moving people from work stations in offices affects interactions, and visibility towards other building components, landmarks or corridor intersections influences wayfinding behaviors. Researchers for many such studies have had to manually perform visibility analysis or create the visibility graph due to the lack of automated tools.

Furthermore, some studies found that impact of visual structure become clearer when certain restrictions were applied, including azimuth and distance radius (Stavroulaki & Peponis, 2003, 2005).

Thus, one specific methodological contribution of this study is to propose a refinement of standard analysis of visual fields. In essence, the refinement consists in drawing a distinction between general visibility, that is visibility equally extending in all available directions from each position in a setting, and directed visibility, that is visibility directed towards a set of pre-selected targets. Furthermore, analysis takes consideration of given restrictions regarding the viewing angle and/or distance from which targets are seen. Armed with those restrictions, it is also possible to conduct visual field analysis of moving users, which implies the need to restrict orientation and field of view.

The coming chapters will demonstrate how directed visibility is applied in three case studies, which range from field observation in real world settings to a more controlled experiment in a simulated 3D environment. Field observation often entails many variables that need to be eliminated and thus is often accused of lacking of interval validity. On the other hand, lab experiment often lacks external or ecological validity or

sometimes adversely affects the behavior of the subject. We hope a broad spectrum of experimental design can achieve a reasonable balance of internal validity and external validity regarding the effect of visual structure. The three case studies are listed below:

- 1) Nursing unit comparison (Chapter 4)
- 2) Spatial use in intensive care unit (Chapter 5)
- 3a) Understanding of painting in simulated exhibitions (Chapter 6)
- 3b) Photograph position (Chapter 7).

CHAPTER 4: THE STRUCTURE OF VISUAL FIELDS IN NURSING

UNITS

4.1 Visibility is important in nursing units

This study explores how directed visibility analysis can be used to quantify the structure of visual fields in nursing units, which is believed to have a significant impact on medical staff members' routine use of space and patients' subjective feelings within the units. These new measures of the visual organization of pertinent elements of the nursing units were aligned with empirical assessment of units from previous studies.

The literature suggests that the layout of nursing units affects nurses' behavior—especially walking and collaborating—as well as patients' perceived quality of care. Sturdavant (1960) compared two intensive care units at Rochester Methodist Hospital in Minnesota, one with a radial design and the other with a single-corridor design. She found that in the radial design nurses walked less frequently to patient rooms because of the increased visual supervision of the patient from the nursing station that this design enabled, and the average time spent within patient rooms was equivalent to that in the single-corridor design. Increased patient visibility in the radial unit also enabled nurse practitioners and nurse managers to participate more in patient care than nurses in the single-corridor design. Later, using pedometers to collect data, Shepley and Davies (2003) confirmed that nursing staff in a 10-bed radial unit walked significantly less than staff in a 24-bed rectangular unit (4.7 steps per minute vs. 7.9 steps per minute).

By eliminating many deficiencies in research design, Trites and colleagues have conducted one of the most rigorous studies on unit assessment (Trites, Galbraith, Sturdavant, & Leckwart, 1970; Trites, Galbraith Jr, Leckwart, & Sturdavant, 1969). They compared the behavioral and perceptual influence of three unit designs built for the purpose of research in Rochester Methodist Hospital: four 27-bed radial units, four 27- to 29-bed double-corridor units, and four 29- to 30-bed single-corridor units. Data on the time utilization of the nursing staff were collected by 14 researchers using a randomized work sampling method over a period of 82 days. The observation procedure involved making a round of the nursing units and recording the location and activity of each staff member. A total of 590 staff members participated in the study.

From the perspective of efficiency, the radial design was more successful because nurses traveled significantly less (0.61 miles on a day shift) in radial units compared to the other two designs (0.79 miles on double-corridor units and 1.08 miles on single-corridor units). After interviewing staff members transferring between a radial unit and a double-corridor unit, the authors also reported that differences in layout can influence the way nursing staff members work together. Specifically, staff members transferred to the double-corridor units reported in general that teamwork was poorer, and those transferred to the radial unit reported that teamwork was more effective after the transfer. More interestingly, interviews and questionnaires indicated that 72% of the patients involved in the transfer preferred the radial unit over the double-corridor unit; the primary reason given for this preference was the patients' feeling of better observation and faster response by nurses in the radial design.

There are good reasons why patterns of visibility are likely to be important to nurses and patients. Nurses must remain continuously aware of the condition of the patients assigned to them, even when they move away from the patient rooms, and patients need to contact nurses for service and care delivery. The direct visibility to nurses can reassure patients that nurses are still aware of them, and therefore, are lead to lower stress among patients. Visibility provides a critical element for maintaining contact and awareness between nursing staff and patients. More recently, visibility has been provided through distributed or decentralized nursing stations.

Previous studies have already established that patterns of visibility influence different kinds of behavior in settings other than nursing units; some of these studies were reviewed in Chapter 2.

This chapter presents a technique for quantitatively characterizing some key differences in the visibility structure of specific floor plans. Essentially, the visibility of a set of preselected targets—patient beds—is analyzed. The results demonstrate that the structure of visual fields directed toward patient beds, analyzed using an original GIS-based extension developed for this study, correlates strongly with aspects of nurse behavior and patient preference.

4.2 Directed visibility analysis

Using directed visibility analysis toward patient beds, the distribution of visibility values could be represented graphically in GIS for the three unit layouts studied in Trites and colleagues' research(1970) (Figure 4.1). The unit of measure is the number of visible patient beds. Our graphics reveal considerable differences in the structure of view fields

toward patient beds across the three units. With similar numbers of beds present in the three units (27 for radial, 29 for single-corridor, and 19 for double-corridor), the directed visibility values vary substantially. The directed visibility value here represents the number of beds that could be seen simultaneously in the setting. For the radial unit, the directed visibility value ranges from 0 to 25, with a mean value of 5.35. For the single-corridor unit, the directed visibility ranges from 0 to 8, with a mean value of 1.9. For the double-corridor unit, it ranges from 0 to 9, with a mean value of 2.37.

Table 4.1: Comparable measures for three unit designs.

measures	Radial	Double-corridor	Single-corridor
Total area (sq ft)	7209	9520	9193
# of beds	27	28	29
Area per bed (sq ft)	269	340	317
# of nursing station	1	1	1
Corridor area(sq ft)	1533	1870	1275
% of corridor area (sq ft)	21.2%	19.6%	13.9%

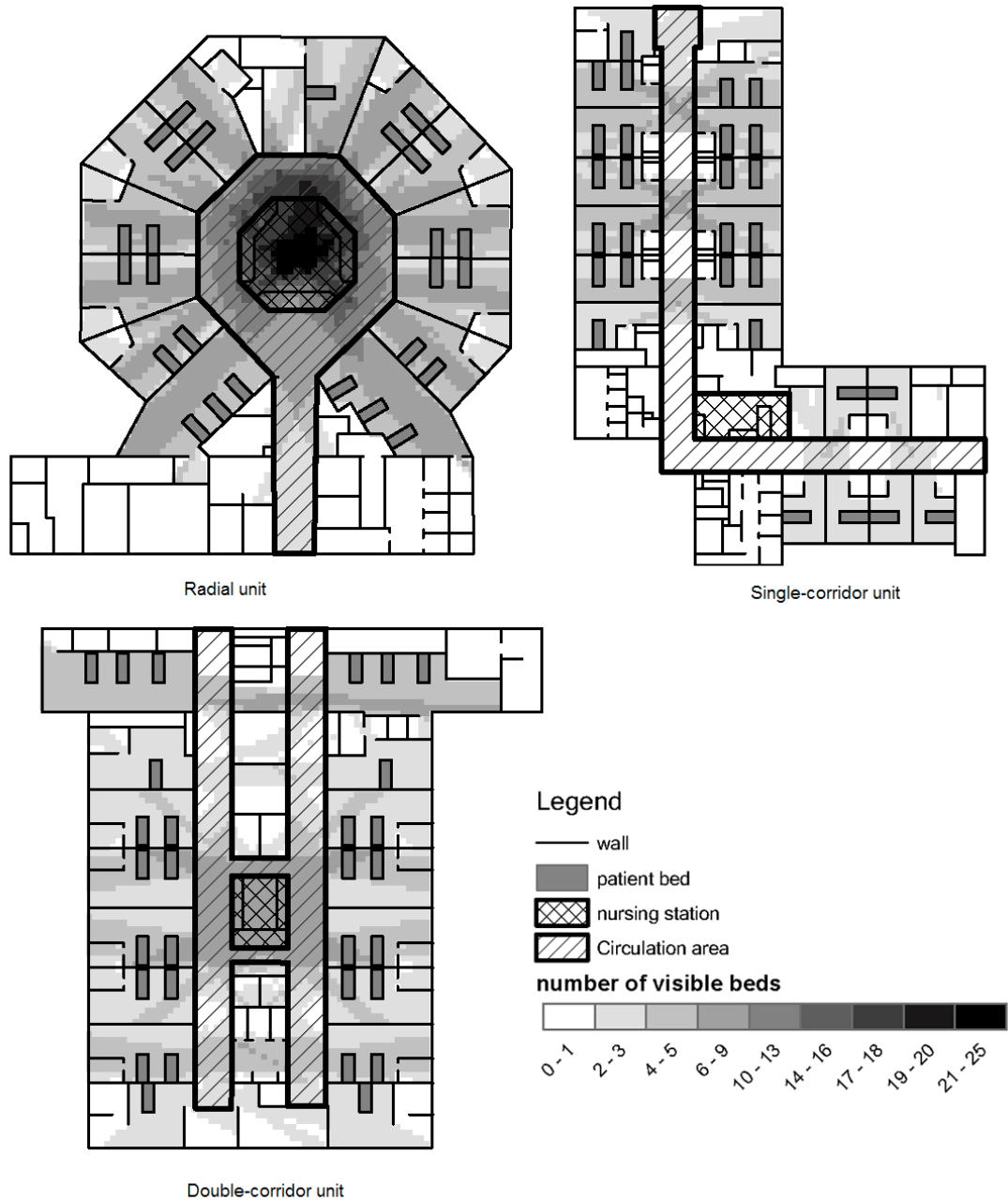


Figure 4.1: The directed visibility analysis for three nursing units. It measures the number of patient beds that are visible from any location within the units. (The darker color represents a higher value.) These three units have substantial differences in visual structure based on the number of patient beds.

4.3 Directed visibility Index

To compensate for different unit sizes, DVI (Directed visibility Index) of circulation areas and nursing stations for the three units was computed and compared (Figure 4.2). DVI provides a comparative spatial quality evaluation of various nursing unit configurations with differing numbers of patient beds.

The algorithm for DVI of a setting can be expressed as

$$DVI = \frac{\sum_{i=1}^n V_i}{n * k}$$

Where V_i is the number of visible targets from node i . n is the total number of nodes (i.e. number of tessellated grids on the floor plan) in the system. k is the total number of targets in the system.

The theoretical value ranges from 0–1. Where the index equals 0, it indicates that none of the targets could be seen from any location. Where index equals 1, it indicates that all targets could be seen from all locations. Again, using the radial unit as an example, its index value is 0.19, which means that 19% of patient beds in the whole unit could be seen simultaneously. At times, in the index of some locations within the units, such as circulation areas or nursing stations are of greater interest than the entire unit. The index can be adapted and computed accordingly.

In terms of the DVI of circulation areas, the radial unit had the highest value, 0.41, followed by the double-corridor unit with 0.12. Surprisingly, the single-corridor

unit had a DVI of only 0.03. The inboard toilet design of the single-corridor unit obstructed views from the corridor and therefore decreased the DVI dramatically.

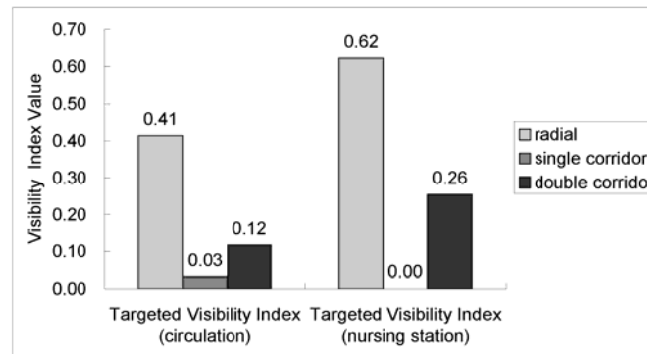


Figure 4.2: The comparison of directed visibility index values in circulation areas and nursing stations for three units.

The radial unit had a higher visibility index than the single- and double-corridor units, and the double-corridor unit had a higher visibility index than the single-corridor unit in both measures.

In terms of the DVI of nursing stations, the rank remained unchanged. The radial unit is 0.62, and the double-corridor unit is 0.26. The single-corridor unit is 0, which indicates that none of the patient beds could be seen from the nursing station in that unit.

The result of the DVI analysis corresponds exactly with Trites and colleagues' original empirical findings. The radial design was superior to the double- and single-corridor designs, and the double-corridor design was superior to the single-corridor design in terms of efficiency and patient satisfaction. Nursing staff on radial units traveled significantly less than nurses on single-corridor units; double-corridor units were next best in this respect. The majority of nursing staff members favored radial units and

believed that the radial design enhanced teamwork and the quality of healthcare delivery. Furthermore, patients also preferred radial units for reasons of close observation and quick response by nursing staff.

4.4 Discussion

Trites and others(1970)implied that the structure of visibility may have caused the different performance among the three unit designs, even though no measures were provided. The literature suggests that improved visibility has at least three important outcomes (Figure 4.3). First, increased visibility for caregivers enables better observation and faster response to patients. Therefore, patient falls and other injuries can be reduced significantly. In a new 56-bed comprehensive cardiac critical care unit within Methodist Hospital in Indianapolis, Indiana, patient falls are reportedly down 67% because of increased visibility and improved patient assistance(Hendrich, Fay, & Sorrells, 2002). Second, increased visibility reduces the time that nurses spend in travel and frees up more time for direct care at the bedside. After comparing a radial unit and a single-corridor design, Sturdavant (1960) found that increased visibility from nursing stations reduced travel distance and time for nurses. Trites and colleagues (1970)also suggested that the reduction in caregiver walking time correlated with an increase in time spent in patient-care activities. Third, greater visibility between staff and patients can increase communication and contact, thus improving patient satisfaction. According to Press Ganey scores, good communication tends to be the single most important factor influencing overall patient satisfaction (Ulrich, Zimring, Joseph, & Choudhary, 2004).

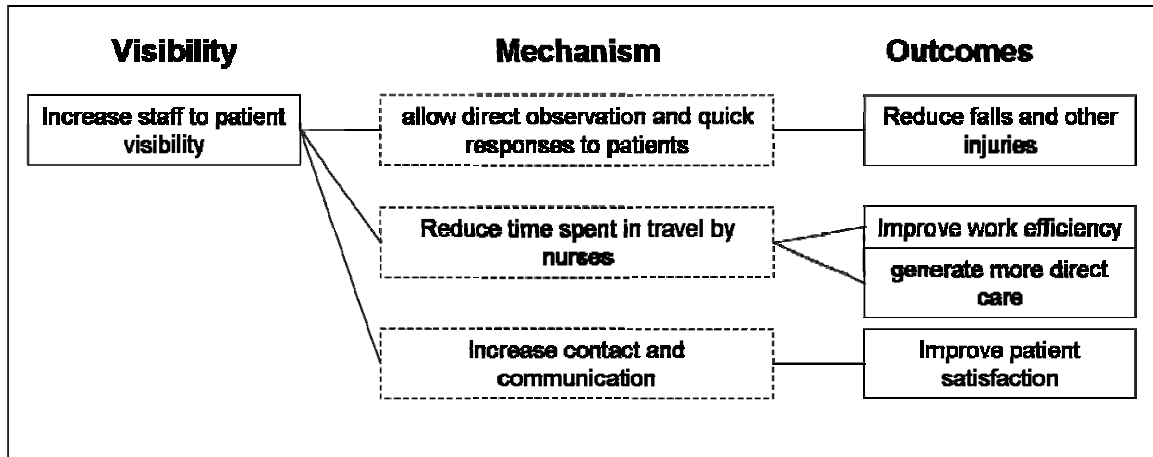


Figure 4.3: The conceptual framework of structure of visibility and its related outcomes. The literature suggested the following outcomes: reduced falls, enhanced work efficiency, more direct care, and improved patient satiation.

Thus, in the context of nursing units, the more precise measurement of visibility seems to indicate an essential link between unit design and behavioral and perceptual consequences. Furthermore, it is not only the general shape of unit configuration (i.e. radial, single-corridor, and double-corridor) that contributes to visual structure, as previous studies suggest. Many details of design may also matter, including the location of doors and windows along corridors, the location of toilets in patient rooms, the location of nursing stations, and so on. For example, if inbound toilets are exchanged for outbound toilets in the single-corridor unit while keeping everything else unchanged, the DVI of the circulation area changes from 0.03 to 0.08. In other words, general classification of the shape of nursing units is not an exact indicator of the quality of visual structure and consequent behavioral outcomes.

Overall, this study leads to two important conclusions. The first is from a methodological point of view. Directed visibility is supported by Gibson's theory of

affordances, which links aspects of both the environment and users. Thus, both objective measures of the environment and subjective perceptions are considered in visibility analysis.

This study proposes the directed visibility index, a quantitative index that applies key visual information and uses it to compare optional unit configurations. The results of the DVI seem to align well with Trites and colleagues' original empirical findings (Trites, et al., 1970). This visibility analysis enhances understanding of the behavioral effects of spatial properties in nursing units.

Second, if the foregoing points are true, some important design applications may be inferred. Designers of healthcare settings should expand their exclusive focus on functional and organizational parameters to also consider the structure of visibility toward key components of the environment. The authors suggest that, by doing the latter, design solutions to address such important issues as work efficiency, patient satisfaction, quality of care, and other concerns may become evident.

CHAPTER 5: SPATIAL BEHAVIORS IN INTENSIVE CARE UNIT

5.1 Introduction

This chapter explores how the behavior of a particular category of building users, specifically nurses working at a Neuro Intensive Care Unit at Emory Hospital, is tuned to the spatial properties of the setting. In particular, the study explores how in moving about and in carrying out normal activities, nurses take into account patterns of visibility and occlusion that arise from the arrangement of boundaries. There are good reasons why patterns of visibility are likely to be important to nurses and therefore register in the spatial trajectories of their working life. Nurses have to remain continuously aware of the condition of the patients assigned to them even when they move away from the patient room. Visibility provides one critical basis for maintaining contact and awareness.

As we mentioned, one specific methodological contribution of this study is to propose a refinement of standard analysis of visual fields. In essence, the refinement consists in drawing a distinction between general visibility, that is visibility equally extending in all available directions from each position in a setting, and directed visibility, that is visibility directed towards a set of pre-selected targets. In this particular case the targets we are interested in are patient beds. It will be shown that directed visibility, analyzed using an original script developed for this study, correlates with aspects of nurses' behavior much more strongly than general visibility. This finding is all the more interesting because while it is very clear for nurses, it does not apply to other categories of users, such as physicians, who have a different role, and hence a different way of registering the setting and tuning themselves to its spatial properties.

5.2 Emory Neuro ICU as A Case Study

These directed visibility measures are produced in the hope they might better predict people's behavior and also to determine what the perceptual qualities of a building might be. To test it, we correlate our measures with the observational behavior in one intensive care unit, and compare the ability of these measures to predict behavior in comparison with more general measures of visibility. The setting, the behavioral variables and visibility variables used in the study are described below.

5.2.1 Setting

The setting is the Neurological Intensive Care Unit the Emory University Hospital (Figure 5.1). It is a 20-bed facility, housed in a recently redesigned unit of the hospital. The staff of the ICU on any given weekday includes 11 registered nurses (baseline staffing level), 1 nurse manager, 3 nurse practitioners, 1 attending physician, 2-3 resident physicians, and consulting inpatient services (e.g., neurology).

5.2.2 Observational Data

Observational data were collected by a group of five observers over a period of two weeks. The aim of the observation was to capture aggregated patterns of distribution of people and their behaviors in the setting. Each observer recorded the location and activity of all people he or she saw on the observation sheets while walking through the setting according to a pre-defined path. Each round took about ten minutes, with 15-minute interval in between rounds. A total of 46 observations were made, which were evenly divided among morning and afternoon shift on each workday.

The behaviors recorded here include interaction (yes/no), surface-using (yes/no), computer-using (yes/no), and identity (nurse/ physician/ nurse practitioner/ family/patient). Later, all the data were input into ArcGIS 9.2 for further analysis. All clusters of observational data within patient rooms were removed from the analysis because these data can be explained by conditions of patient rather than the spatial effects. The aggregated data show 946 counts of people present in the setting including 320 physicians (D) and 626 nurses (RN), with almost half of people are interacting with others (Figure 5.1).

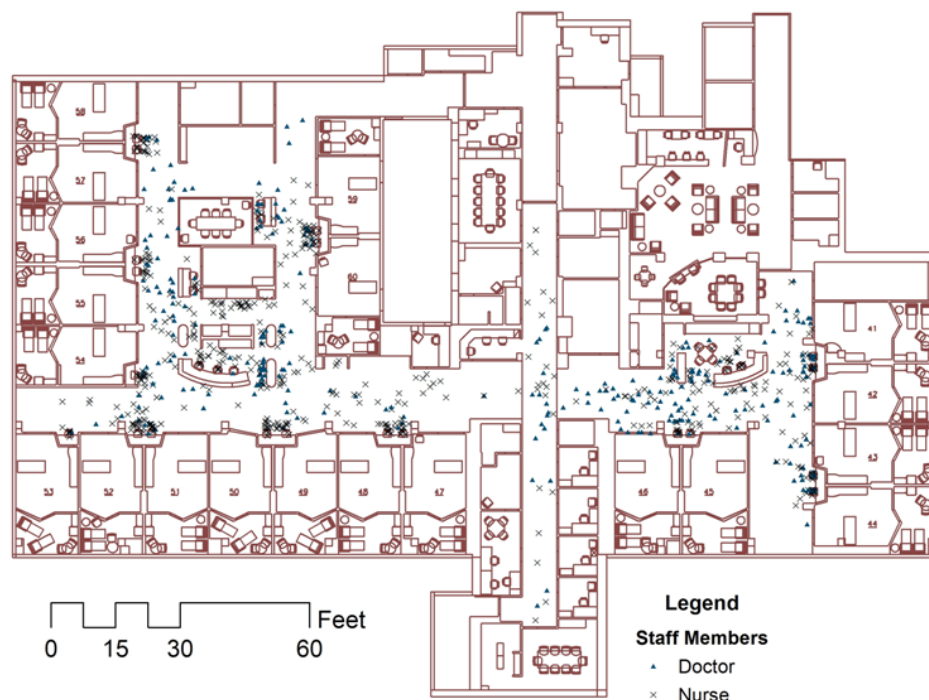


Figure 5.1: The floor plan of the setting and the aggregated distribution of medical staff according to the empirical observation.

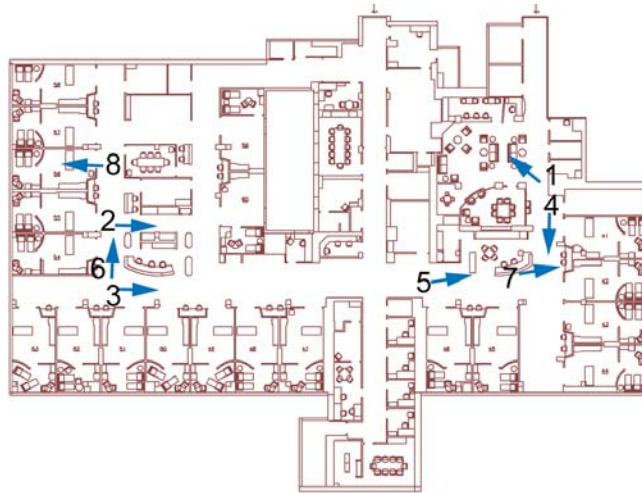


Figure 5.2: The photograph locations of Emory Neuro ICU.
1) family waiting room, 2) Supply area 3) Nursing station, 4) corridor, 5) nursing station,
6) nursing station, 7) alcove, 8) patient room.



Figure 5.3: The photographs of Emory Neuro ICU, photographer: Charles Cadenhead.

5.3 Data analysis and results

5.3.1 Visibility Variables

Nurses in this setting are likely to pay close attention to their patients, who are severely ill and immobile. We test the proposition that visibility of patient impacts the distribution patterns of staff members here. Thus, the targeted visual connectivity value is based on patient beds in this unit. The unit of measure is the number of unique patient beds that are visible from any given location. With the script we developed, visibility of patient could be calculated and represented graphically (Figure 5.4). The value ranges from 0 to 9, which is the minimum and maximum number of beds could be seen simultaneously in the setting.

We use number of people per unit area as our dependent variable, which is calculated by dividing the number of people at each level of visibility of patient value with corresponding number of unit tiles at that level.

First, it is obvious to see the distribution of visibility of patient is not equal (Figure 5.5). Most points have a visual connectivity value of less than 2, meaning that at most points in the unit people can see two or less beds. By computing the density of occupancy, rather than absolute occupancy scores per directed visibility zone, we normalize for the uneven area of the various visibility zones. Second, all points at each level of targeted visual connectivity value have constant visual information (i.e., the number of beds visible from a point). By aggregating the data according to visibility of patient, we can focus on the effect of visual structure.

We also compute generic visual connectivity, the standard output of Depthmap. It tessellated the floorplan of the unit into a regular grid in which each grid is associated

with a centroid point. Generic visual connectivity measures the number of points that are visible from a point, which roughly represents to the size of isovist (Figure 5.6). The value ranges from 85 to 4555, which is the minimum and maximum number of points could be seen simultaneously in the setting.

In order to study how generic visual connectivity predicts behavior as compared to targeted visual connectivity, and given that there are only 10 targeted connectivity values, the generic visual connectivity was divided into 10 levels with equal intervals, and recoded into an ordinal variable which ranges from 1-10. The following figures show the number of points and people at each level of recoded generic visual connectivity value (Figure 5.7).

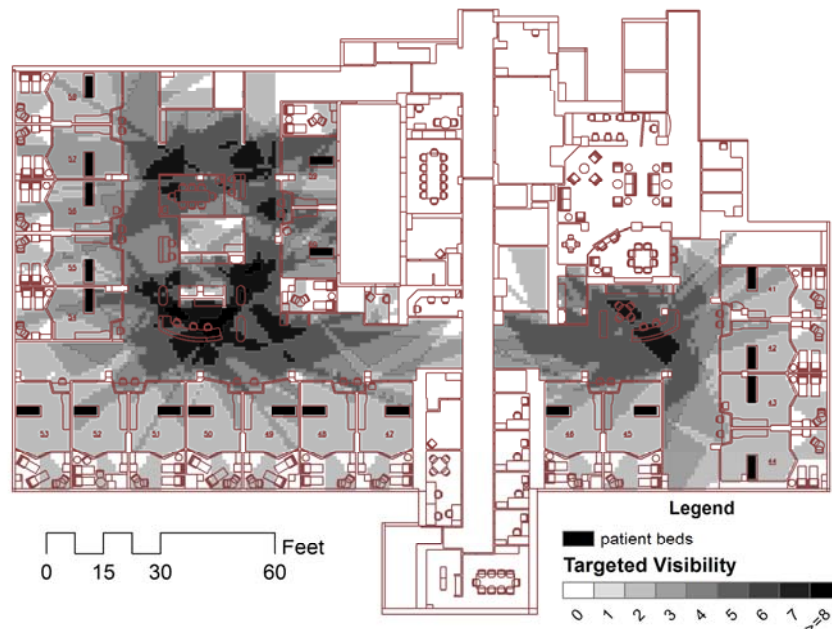


Figure 5.4: The visibility of patient in the unit.
It measures the number of patient beds that are visible from any location (The darker color represents higher values). It has 10 values which range from 0-9.

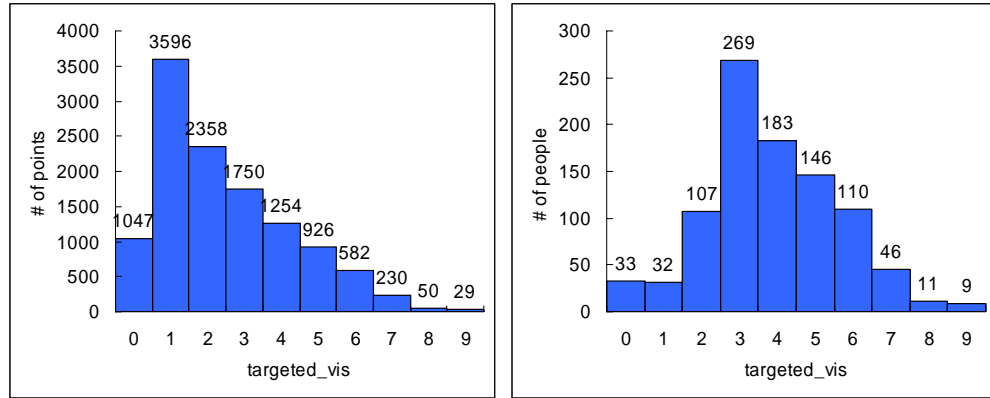


Figure 5.5: Left: the number of points at each level of directed visibility value. Right: the number of people present at each level of directed visibility value.

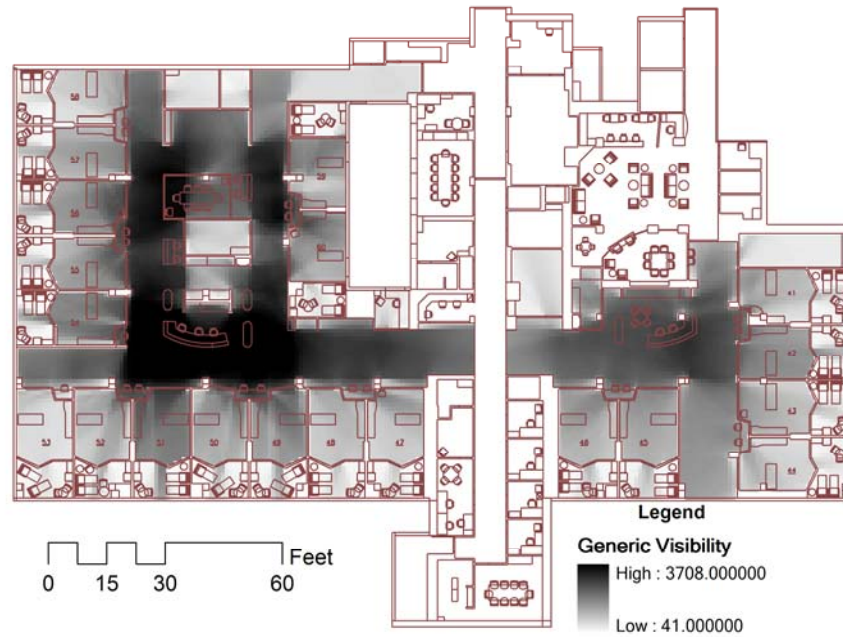


Figure 5.6: The visibility of open space in the unit. It measures the number of points that are directly visibility from any locations (The darker color represent higher values). The value ranges from 85 to 4555.

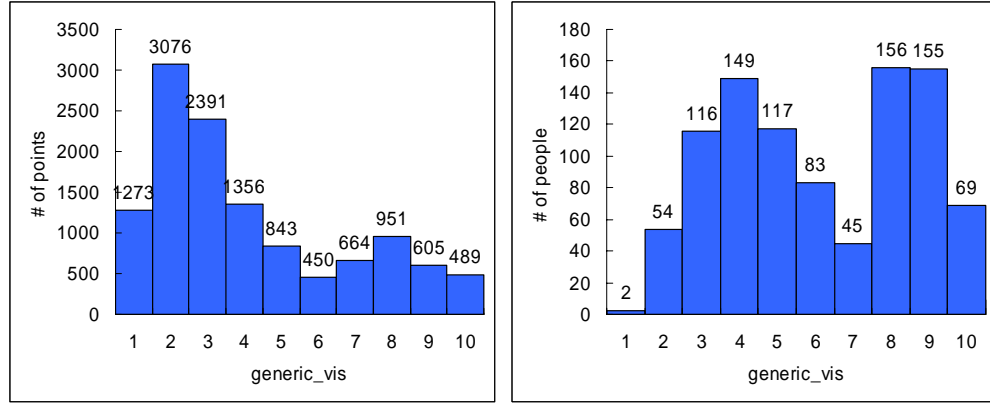


Figure 5.7: Left: the number of points at each level of generic visibility value, which is broken into 10 levels with equal intervals. Right: the number of people presented at each level of generic visibility value.

5.3.2 Correlational Analysis of Visibility Variables

Considering generic visibility at all points, the density (number of people per point on the visibility grid) of all staff members at specific levels of generic visual connectivity shows a very significant positive correlation with the rank of ten levels (Pearson's correlation coefficient $r=0.786$, $p=0.007$). Staff members are composed of nurses and physicians who have different task assignments. It is worthwhile to decompose the data into different categories: the nurses and physicians. They show different patterns of distribution in the setting. Physicians show the same pattern of distribution with respect to levels of visibility, i.e. the density of physicians at any level of visibility is highly correlated with the rank of the level ($r=0.805$, $p=0.005$). For nurses, however, the corresponding correlation is both weaker and barely significant ($r=0.634$, $p=0.049$). We further split the data according to interacting status (interacting and not-interacting). The correlations for the interacting physicians and not-interacting physicians are significant ($r=0.811$, $p=0.004$ and $r=0.747$, $p=0.013$ respectively). For nurse, the

correlation for interacting nurses is also significant ($r=0.817$, $p=0.004$), but that for non-interacting nurses is not ($r=0.359$, $p=0.309$).

Considering directed visibility of patient at all points, the density (number of people per point on the visibility grid) of all staff members at specific levels of targeted visual connectivity shows a nearly perfect positive correlation with the targeted visual connectivity value ($r=0.952$, $p<0.001$). Physicians show a much weaker and non-significant correlation ($r=0.482$, $p=0.158$). Nurses show a high correlation with respect to levels of visibility of patient, that is the density of nurses at any level of visibility of patient is highly correlated with visibility of patient value ($r=0.924$, $p<0.001$). Again, we further split the data according to interacting status. Both correlations for the interacting physicians and non-interacting physicians are not significant ($r=0.593$, $p=0.071$ and $r=0.208$, $p=0.565$ respectively). However, the interacting nurses and non-interacting nurses show different patterns. The correlation for interacting nurses is strong and significant ($r=0.894$, $p<0.001$), but that for non-interacting nurses is not ($r=0.566$, $p=0.088$).

To sum up, visibility of patient is more strongly correlated with the density of all staff members compared with generic visual connectivity. It is also more strongly correlated with the density of all nurses and the density of the interacting nurses. Generic visual connectivity is more strongly correlated with the density of physicians, both interacting and non-interacting ones compared with targeted visual connectivity.

The presence of work surfaces in this setting, including central nurse stations, distributed work stations and computer stations, may also influence the distribution of staff members. Thus, it may threaten the internal validity for the behavioral impact of visual structure. To rule out this alternative explanation, we performed the previous

analysis again with all staff members engaging work surface and/or computer excluded from our record and correlational test. Our new data set has 515 counts of staff members, who are engaging neither work surface nor computer, including 199 physicians and 316 nurses.

Considering generic visibility, the correlation for all staff remains strong and significant ($r=0.786$, $p=0.007$). The correlation for physicians is stronger compared with that for nurses ($r=0.820$, $p=0.004$ and $r=0.732$, $p=0.016$ respectively). The correlations for the interacting physicians and non-interacting physicians are both significant ($r=0.817$, $p=0.004$ and $r=0.735$, $p=0.015$ respectively). The correlations for the interacting nurses and non-interacting nurses are also both significant ($r=0.753$, $p=0.012$ and $r=0.689$, $p=0.027$ respectively).

Considering directed visibility of patient, the density of all staff members at specific levels of visibility of patient is still strongly correlated with visibility of patient value ($r=0.916$, $p<0.001$). The correlation for physicians is weak and not significant ($r=0.420$, $p=0.227$). The correlation for the interacting physicians is barely significant ($r=0.639$, $p=0.047$), and that for non-interacting physicians is not significant ($r=0.013$, $p=0.971$). The correlation for nurse remains high ($r=0.945$, $p<0.001$), with the correlation for interacting nurses remaining high ($r=0.890$, $p<0.001$), but that for non-interacting nurses is not ($r=0.331$, $p=0.351$).

After all staff members engaging work surfaces were removed from our analysis, the correlations become slightly stronger, but the overall pattern remains almost unaffected. Visibility of patient is still more strongly correlated with the density of all staff members, nurses, and interacting nurses compared with generic visual connectivity.

Generic visual connectivity is still more strongly correlated with the density of physicians, both interacting and not-interacting.

The results indicate that nurses especially interacting nurses are more tuned to directed visibility and physicians are more tuned to generic visibility. In other words, proportionally more nurses can be expected in the areas with higher visibility of patient, while proportionally more physicians can be expected in the locations associated with a larger view field.

5.4 Discussion

The explanation for the observed behavioral patterns of nurses and physicians can be linked to their different roles.

In this ICU, each nurse is normally assigned to two adjacent patients, and nurses are required to pay close attention to their patients. At the same time, nurses need to interact with other people for all kinds of reasons, including transmission of work-related skills and knowledge, communication and socialization, and reaching out for help. The situation is true in this study, with more than half of observed nurses (333 of 626 counts) interacting with others. When two nurses need to interact with each other, the preferred locations should be within the overlapping isovists from their patients. They consciously or unconsciously negotiate a location to talk where both of them can keep their patients under close observation. On the other hand, the physicians are not anchored to any particular room, and they are required to round among all patient rooms. They tend to locate themselves where they can see a larger area, which gives them a better awareness of the surrounding environment and on-going situation.

Overall, this study leads to three important conclusions. The first is people with different roles (nurses vs. physicians) are tuned to different features of environment. The distribution of nurses in the setting is a result of deliberate efforts of individuals who position themselves towards areas that have high visual access to patients, especially during interactions. The distribution of physicians can be explained by the preference for a position where they can maximize their awareness of the surrounding environment.

Secondly, from a methodological point of view, by drawing a distinction between generic visibility pattern and directed visibility pattern, we can enhance the applicability of visibility analysis to studies of the behavioral impacts of spatial properties.

Finally, together with findings from previous chapter, we emphasize the importance of the structure of visual fields in nursing units and intensive care units. Healthcare designers should pay the proper attention to local effects of spatial configuration created by visibility conditions (for instance hot-spots where more than one bed is visible at a time) rather than the overall qualities like perceived openness, in order to address important issues like work efficiency, transmission of work-related skills and knowledge and other healthcare workplace issues.

CHAPTER 6: CO-VISIBILITY AND UNDERSTANDING OF PAINTINGS

6.1 Introduction

It is often argued that mental representations of both concrete concepts and abstract concepts are grounded in sensory-motor experience (Gibson, 1979; Lakoff & Johnson, 1980, 1999; Piaget, 1967). Concrete concepts are physical entities in the world (e.g., table). A person gains physical experiences of such concept through perception (e.g., seeing a table) and interaction (e.g., writing on a table or walking around a table). According to the theory of embodied cognition, such sensory-motor experiences build the mental representations of the concept. In contrast, abstract concepts (i.e., ideas) are not physical entities in the worlds, thus a person cannot have direct physical experiences with abstract concepts. However, some theories provide a framework in which mental representations of abstract concepts are also grounded in sensory-motor experiences. For example, Lakoff and Johnson argue that people represent abstract concepts in terms of concrete concepts by metaphorical mapping (Lakoff & Johnson, 1980, 1999). Physical experiences result in the formation of image schemas, which are conceptual structures that represent spatial relations and movements in spaces. Image schemas of concrete concepts are mapped onto abstract concepts. This metaphorical link between concrete and abstract concepts is formed by co-occurrence of the two concepts in one's experience during childhood (Mandler, 1992).

There is a growing body of evidence supporting the link between abstract concepts and sensory-motor experience, such as time and spatial displacement (Casasanto & Boroditsky, 2008), power and verticality (Schubert, 2005), and similarity and physical distance (Boot & Pecher, 2010; Casasanto, 2008). For example, estimations of presentation times of visual stimuli (e.g., a moving dot) are influenced by spatial displacements of the stimuli (e.g., the distance over which the dot moves) (Casasanto & Boroditsky, 2008). The result suggests that people use the mental representation of space in order to fully understand time. The judgments of the power of animals depicted are influenced by the locations of the animal pictures on the computer screen (Schubert, 2005). Participants give higher ratings to animals when they were presented at the top of the screen compared to those at the bottom of the screen. Those results indicate that power is partly represented by verticality.

Several studies reveal that spatial distance influences the perceived similarity among pairs of objects. Casasanto (2008) reports that similarity ratings for pairs of words or pictures are influenced by the distance between the pair of stimuli as they appeared on the computer screen serially. However, the direction of influence depends on the type of tasks. The pairs of words and pictures for conceptual judgments are rated as more similar if the stimuli are presented closer together. By contrast, the pairs of pictures for perceptual judgments of visual appearance are rated as less similar if the stimuli are closer. Casasanto believes that when perceptual information is not available in the stimuli (pairs of words) or is not relevant to the task (conceptual judgment for pairs of pictures), participants tend to use the heuristic knowledge that proximity correlates with similarity. By contrast, when perceptual information is available in the stimuli and is relevant to the

task, participants may have judged close stimuli to be less similar because proximity facilitates noticing small differences.

Boot & Pecher (2010) also report that spatial distance influenced speeded similar/dissimilar decision on the color of a pair of squares. Performance regarding similar colors is better when stimuli are presented at shorter distances on screen, whereas performance regarding dissimilar colors is better when stimuli are presented at longer distances.

6.2 A study of museum space: does arrangement matter to categorization?

The topic is of importance in architecture for the following reason. We want to know if the manner in which we position things in space conveys subtler ideas than the mere commanding of attention (placing a key garment on axis at Ahlens City department store (Koch, 2007); placing a painting on axis at the Sainsbury Wing of the National Gallery (Tzortzi, 2004)).

In Chapter 2, we have already pointed out that museum curators use the spatial layout of objects, especially co-visibility among objects, to articulate the ideas and relations between objects and groups. For example, Psarra (2009) showed that curators at MoMA accentuate the complex nature of modern art by emphasizing multiple visual relations among displays in different galleries.

However, very few empirical studies demonstrate the link between arrangement of displays and the visitor's understanding of those displays in museum space. To address the gap, the present study investigates whether the arrangement of displays influences the perceived salience of displays in simulated 3D museums.

The simulated 3D environment has been widely used in the topic of wayfinding and spatial cognition (Aginsky, Harris, Rensink, & Beusmans, 1997; Burigat & Chittaro, 2007; Cubukcu & Nasar, 2005; Jansen-Osmann, Schmid, & Heil, 2007; Jansen-Osmann & Wiedenbauer, 2004a, 2004b; Janzen, 2006; Janzen, Herrmann, Katz, & Schweizer, 2000; Janzen, Schade, Katz, & Herrmann, 2001; O'Neill, 1992; Steck & Mallot, 2000; Werner & Schindler, 2004; Wiener, Schnee, & Mallot, 2004). It is also a good choice for the present study for the following reasons.

- 1) We can vary the arrangement of displays and the layout of the space.

- 2) We can accurately record the location and orientation of the observer's movement in the space. Thus, we can analyze the visual fields of the moving participants with relative accuracy.

- 3) We can also control the physical environment, such as the ambient lighting level, and the presence of other observers in the space, and thus we can tease out those factors.

Furthermore, all the cited studies mentioned in the previous section use 2-dimensional (2D) representations of objects on computer screens as stimuli in their studies. The 3D virtual environment experiment may be of interest to cognitive science and enrich 3D studies such as those mentioned above.

6.3 Method

For the purposes of this study collections of art works are treated as consisting not merely of a list of individual works but also of a number of themes. A theme comprises a set of works that share the same subject matter or the same underlying visual structure. The collection used in the study comprises etchings, lithographs, woodcuts and linoleum

cuts by Escher(Ernst, 1976; Escher, Bool, & Locher, 1982). Escher's works are chosen because they cover a wide range of subject matter, from depictions of landscapes and portraits to depictions of abstract patterns. The subject matter includes both scenes and patterns that could exist in the real world as well as depictions of scenes or patterns that are paradoxical or impossible to realize in normal 3-D space. All works, however, have clear delineation and are easy to grasp pictorially(Ernst, 1976). Desktop virtual environments are used to test whether participants visiting virtual exhibitions of Escher's works would rank or rate conceptual themes as more salient according to whether member paintings are more co-visible than member paintings of other conceptual themes. Participants actively explored four simulated exhibitions of M.S. Escher's works sequentially. Each exhibition places a pair of conceptual themes in either high or low co-visibility conditions. Participants rate pairs of themes in terms of perceived salience of conceptual themes after virtually exploring each exhibition.

The degree of co-visibility associated with a theme is measured by the average number of member paintings that can be seen simultaneously from all occupiable locations. It is analyzed with an extension on the ArcGIS developed by the author (see Chapter 3).

6.3.1 Participants

Forty-two undergraduate and graduate students from Georgia Institute of Technology participated this experiment, with approximately equal numbers of men (22) and women (20).

6.3.2 Materials

Virtual exhibitions were simulated with the Unreal Engine 2 software, a real-time 3D environment generator game engine. The viewpoint was set at the height of 1.6m, average eye level. The game engine displays the scenes in color at a rate of approximately 20 frames per second. Participants sat in front of 20-inch monitor (1200 x 1024 pixel resolution) and controlled their movement in the simulated environments via keyboard (i.e. up arrow for forward, down arrow for back, left arrow to move left, and right arrow to move right) and mouse (left for look left, right for look right).

Four exhibition layouts whose overall dimensions are adapted from the pavilions of the High Museum of Art Atlanta were used in the virtual environment. The pavilions of the High Museum of Art were taken as a convenient shell because historically they have lent themselves to several interior exhibition arrangements based on very different design principles (Zamani, 2008) and because they are well suited for showing works of relatively small size. The layouts can be generally described as free-standing, overlapping, ring, and cellular. All four layouts cover a rectangular area of 13.6m x 18.6m or 47 ft x 81 ft (Figure 6.1).



Figure 6.1: Four exhibition layouts used in the experiment. Each exhibition displays two themes with five works in each theme in addition to a six landscape works (total 16 paintings). One theme was arranged in a high co-visibility condition and another in a low co-visibility condition in each layout.

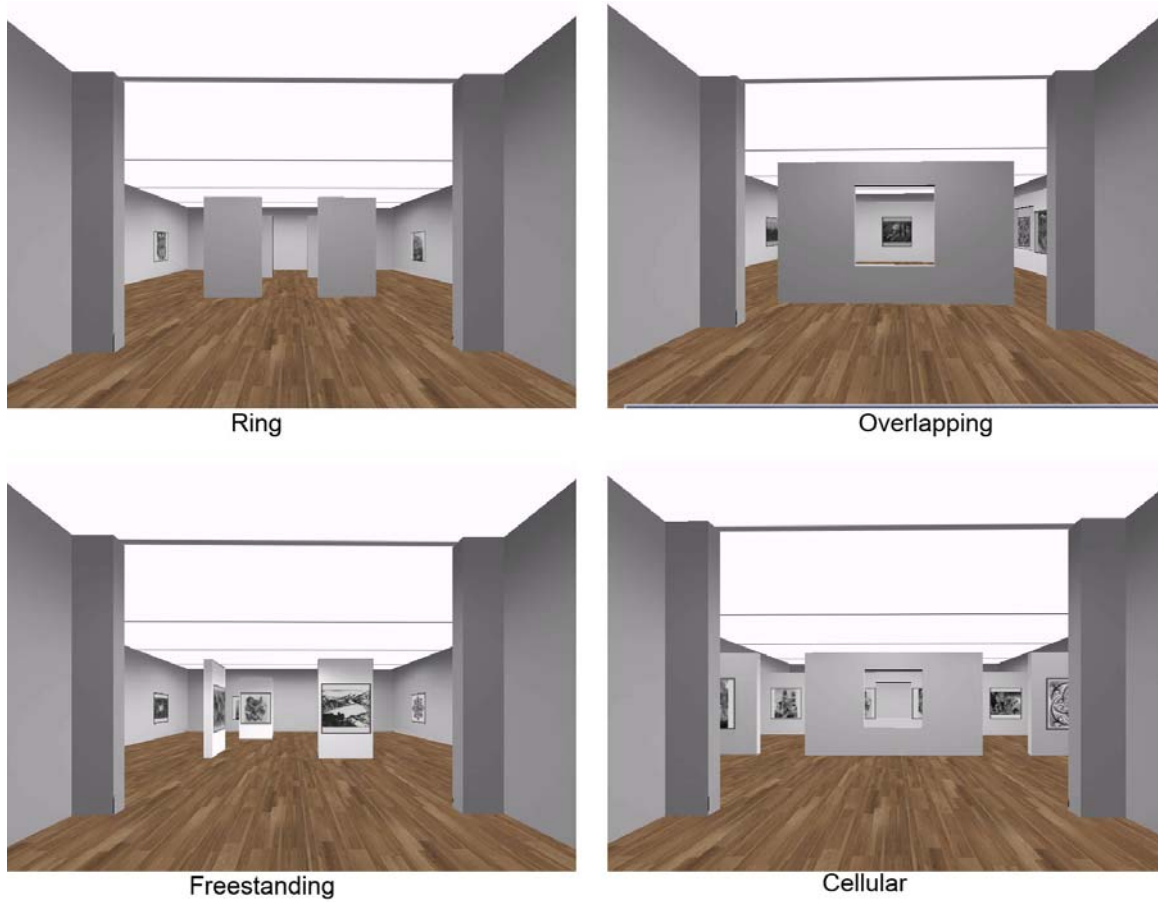


Figure 6.2: Photographs from the starting location of each layout.

Table 6.1: Comparable measures for four layouts.

measures	Ring	Overlapping	Freestanding	Cellular
Area (sq m)	253	253	253	253
# of displays	16	16	16	16
Partition wall length (m)	12.8	16.6	6.4	30.8

Eight different conceptual themes from M.C. Escher's work were grouped into four pairs, star-letter (Figure 6.3), tree-church (Figure 6.4), nude-portrait (Figure 6.5), and

building-fish (Figure 6.6). Each theme included five works. Each exhibition displayed a theme pair in addition to six out of twenty-four landscape works (Figure 6.7) (a total of 16 paintings). Two themes were arranged in a high co-visibility condition and a low co-visibility condition in each layout. Each painting was scaled to the same size (5 ft x 5 ft, or 1.5m x 1.5m, while maintaining the original proportion) to control the impact of painting size on perception. Each painting was displayed at eye level on vertical wall surfaces. The landscape works were useful for ensuring that wall surfaces were covered with displays at a relatively uniform density, so that no groupings are suggested by the way in which paintings are arranged on an individual wall surface.

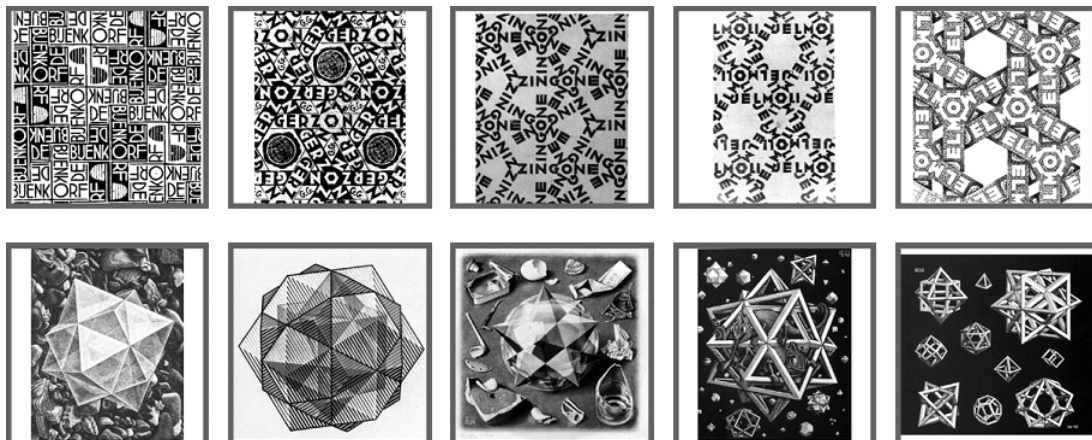


Figure 6.3: The theme pair of star-letter.



Figure 6.4: The theme pair of tree-church.



Figure 6.5: The theme pair of nude-portrait.

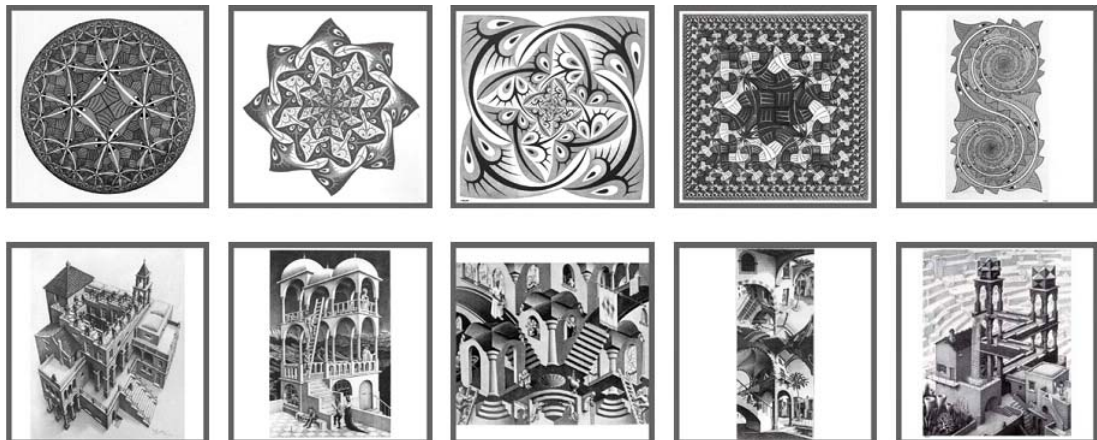


Figure 6.6: The theme pair of building-fish.



Figure 6.7: The landscape works.

6.3.3 Design and procedure

The participants were tested individually in a single session that lasted approximately 20-40 minutes. First, they received a practice trial to familiarize themselves with navigation in the virtual environment.

After the practice trial, participants actively explored all four exhibitions sequentially in one of four counterbalanced orders (1-4-3-2, 2-1-4-3, 3-2-1-4, 4-3-2-1). Thus, the sample for analysis includes 168 trials in total (42 x 4). The participants saw each theme pair and each layout only once. The assignment of theme pairs to layouts was counterbalanced across participants. The assignment of theme pairs to co-visibility conditions was also counterbalanced across participants.

All participants started at the same location at the beginning of each exhibition. They were instructed to view all art works in the exhibition. The visit through the exhibition is self-paced, and is immediately followed by the tasks below.

- Presentation choice: Choose which theme (A or B) was more clearly presented in the exhibition.
- Presentation rating: Rate the clarity with which theme A was presented by virtue of the arrangement of exhibition on a scale from 1 (not at all clear) to 9 (very clear).
- Presentation rating: Rate the clarity with which theme B was presented by virtue of the arrangement of exhibition on a scale from 1 (not at all clear) to 9 (very clear).
- Expression choice: Choose which theme (A or B) was more clearly expressed in the paintings themselves.

- Expression rating: Rate the clarity with which theme A was expressed in the paintings themselves on a scale from 1 (not at all clear) to 9 (very clear).
- Expression rating: Rate the clarity with which theme B was expressed in the paintings themselves on a scale from 1 (not at all clear) to 9 (very clear).

The distinction between the “presentation questions” and the “expression questions” is made with a particular intent in mind. In asking about “presentation” we sought to determine whether “co-visibility” plays a role in how people assess the clarity of presentation of a theme. The reason we are interested in this question is its impact on exhibition design: should we strive to use co-visibility in particular ways, to convey “themes”? In asking about “expression” we wonder whether presentation affects judgment about content. Thus, the aim is to test whether co-visibility affects judgment about the intrinsic conceptual and visual clarity of a theme, versus the clarity of the presentation of the theme by virtue of placement within a particular exhibition layout. After finishing those questions for each exhibition, the participants were asked to revisit the same exhibition and to find a location from which the greatest number of paintings belonging to each theme can be seen and photographed. The photographing procedure and related results will be discussed in the following chapter in detail.

6.4 Results

6.4.1 Presentation ratings and expression ratings

In 10 out of 168 trials, there was a conflict between the ranking of the themes according to the direct comparative question and the ranking implicit in the two separate evaluation questions. The 10 trials were removed from the analysis.

Participants were asked to choose which theme was more clearly presented in the exhibition or more clearly expressed in the paintings themselves. The result shows that in 98 out of 158 trials (Figure 6.8), the participants judged that the theme in the high co-visibility condition was more clearly presented than that in the low co-visibility condition (the presentation choice task). In only 76 out of 158 trials, did the participants judge that the theme in high co-visibility condition was more clearly expressed in the paintings themselves than that in low co-visibility condition (the expression choice task).

The binomial test shows in the presentation choice task, the choice of themes in high and low co-visibility condition (62:38 split) is significantly different from a random 50:50 split ($p=.003$). In the expression choice task, the choice of theme in high and low co-visibility condition (48:52 split) is not significantly different from a 50/50 split ($p=.691$). So, initially, this indicates that presentation and expression behave differently, as we would expect. The placement of paintings in the exhibition layout does not appear to affect the retrospective evaluation of the intrinsic clarity of their classification by theme. It does affect the sense of whether the theme was well-presented.

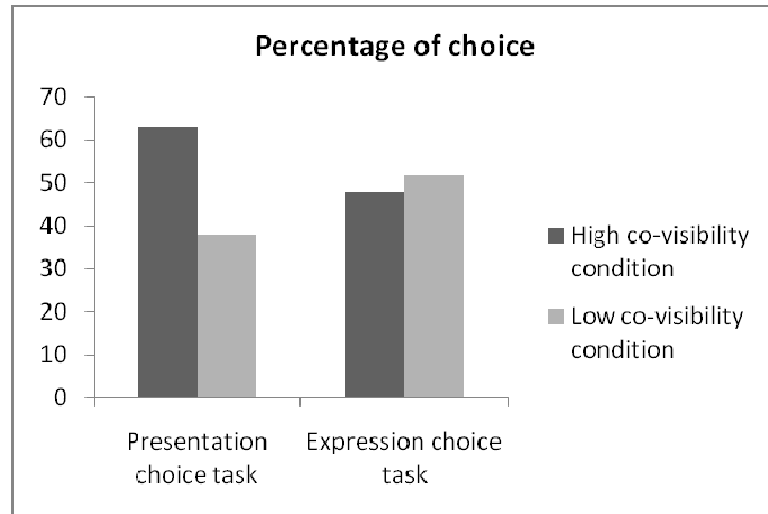


Figure 6.8: The preference in presentation task and expression task. The participants were asked choose which theme (in high or low co-visibility condition) was more clearly presented in the exhibition or more clearly expressed in the paintings themselves. The binomial test shows in the presentation evaluation task, the preference for the theme in high co-visibility condition (62%) is significantly different from chance. While in the expression preference task, the preference (48%) is not significantly different from chance.

Because in each trial, participants were asked to rate both the high co-visibility and the low co-visibility themes, we used paired-samples t-tests to compare the ratings for themes in different co-visibility conditions.

There was a significant difference in the presentation ratings for high co-visibility ($M=7.01$, $SD=1.57$) and low co-visibility ($M=5.68$, $SD=1.65$) conditions; $t(157)=5.89$, $p < .001$ (Figure 6.9). These results suggest that the co-visibility condition affects the perceived clarity of presentation of a theme. Specifically, our results suggest that when the theme is located in high co-visibility condition, the perceived salience of the theme increases.

There was not a significant difference in the expression ratings for high co-visibility ($M=7.09$, $SD=1.78$) and low co-visibility ($M=7.40$, $SD=1.58$) conditions; $t(157) = -1.47$, $p = .143$ (Figure 6.9). The results suggest that themes in high co-visibility conditions were not judged to be more clearly expressed in painting themselves than those in low co-visibility conditions.

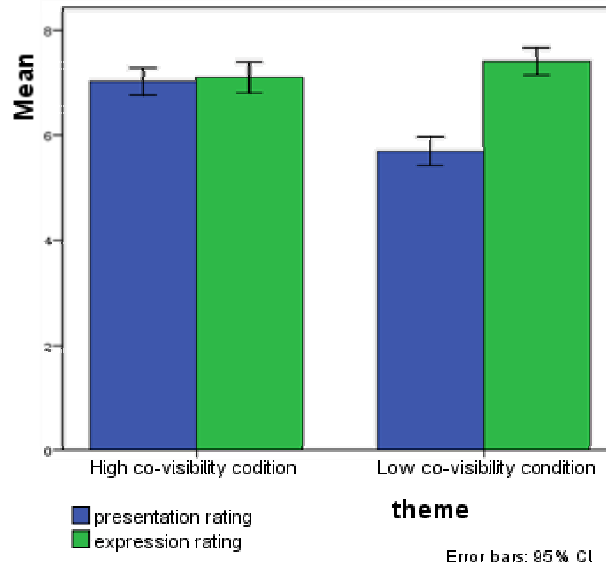


Figure 6.9: The ratings in presentation task and expression task.

The participants were asked to rate the clarity with which themes in high or low co-visibility condition were **presented by virtue of the arrangement of exhibition** on a scale from 1 (not at all clear) to 9 (very clear). The presentation ratings for the themes varied significantly as a function of their co-visibility conditions. Themes that are located in high co-visibility conditions were rated more clearly in terms of perceived salience. The participants were also asked to rate the clarity with which themes in high or low co-visibility conditions was **expressed in the paintings themselves** on a scale from 1 (not at all clear) to 9 (very clear). The expression ratings for the themes did not vary significantly as a function of their co-visibility conditions.

6.4.2 Co-visibility measures

Given that we can quantify co-visibility condition as a continuous variable rather than a two-level variable (high or low), we computed Pearson product-moment correlation coefficients to assess the relationship between objective co-visibility measures applied to the settings and perceived salience of conceptual themes, which is measured by the ratings of our participants.

We developed the following five measures for co-visibility:

1) Global co-visibility. Global co-visibility is based on the average number of paintings that could be seen from all locations in the exhibitions. First, a uniform grid of observation points at a .3meter interval was superimposed on the top layer of a floor plan. The average number of visible works was computed across all locations. The analysis is performed separately for the theme in the high co-visibility condition and the theme in the low co-visibility condition for each layout. The value is only dependent on spatial layout, thus we have a total of eight values for eight themes in four exhibition layouts.

2) Path co-visibility with a 360-degree view. To take the participant's movement into consideration, we developed the co-visibility analysis based on the path taken by the participant during exploration. The individual path was recorded as a series of points at intervals of .05 second. The path co-visibility with a360-degree view is based on the average number of paintings that could be seen from the individual paths without consideration of the orientation and field of view of the participants. Again, the analysis is performed for the theme in the high co-visibility condition and the theme in the low co-visibility condition for each path. For example, we have a path with three points (Table

6.2), thus the path co-visibility for the theme in the high co-visibility condition is computed as $f/3$.

3) Path co-visibility with azimuth restriction. In the experiment, not only the locations but also the orientations of the movements were recorded at intervals. Thus, the path co-visibility with azimuth restriction takes consideration of the orientation and fields of view. In other words, it is based upon what paintings were shown on the computer screen during the experiment. In the example shown in Table 6.2, the path co-visibility with azimuth restriction for theme A is computed as $a/3$.

4) Relative path co-visibility. To take noise into account, relative path co-visibility is used. It is ratio of the total accumulated number of visible paintings from one theme to the total accumulated number of visible paintings from all themes for the whole path, with the azimuth consideration. Using the same example, the relative path co-visibility for theme A is computed as $a/(a+b+c)$.

Table 6.2: An example path taken by a participant.
The path is recorded as a set of points, and the number of visible paintings is also recorded accordingly.

Path Point ID	Number of visible paintings from theme A with 360 degree of view	Number of visible paintings from theme A with azimuth restriction	Number of visible paintings from theme B with azimuth restriction	Number of visible in-fill paintings with azimuth restriction
1	f_1	a_1	b_1	c_1
2	f_2	a_2	b_2	c_2
3	f_3	a_3	b_3	c_3
Sum	$f=f_1+f_2+f_3$	$a=a_1+a_2+a_3$	$b=b_1+b_2+b_3$	$c=c_1+c_2+c_3$

5) Path co-visibility with azimuth restriction and angular size restriction. The last refinement takes consideration of the angular size restriction in addition to the azimuth restriction. A painting's angular size is the horizontal angle a viewed painting subtends at the eye. Any paintings smaller than the angular size are excluded from the analysis. The angular size takes consideration of both the distance and orientation to a painting. The angular size of 2, 4, 8, 16, and 32 degrees were tested.

6.4.3 Correlations between co-visibility measures and ratings

The presentation rating for themes shows a positive correlation with the global co-visibility measure (Pearson's correlation coefficient $r=.272$, $p<.001$) (Figure 6.10). It is strongly correlated with path co-visibility with a 360-degree view ($r=.376$, $p<.001$). It is more strongly correlated with path co-visibility with azimuth restriction ($r=.536$, $p<.001$), and even more strongly correlated with relative path co-visibility ($r=.631$, $p<.001$). The presentation ratings are also correlated with path co-visibility with azimuth restriction and angular size restriction of 2, 4, 8, 16, 32 degree ($r=.549$, $.575$, $.588$, $.585$, $.300$ respectively, $p<.001$).

More interestingly, the global co-visibility measure is strongly positively correlated with path co-visibility with a 360-degree view ($r=.884$, $p<.001$) and path co-visibility with azimuth restriction ($r=.552$, $p<.001$) (Figure 6.11).

In sum, the path co-visibility with azimuth restriction and relative path co-visibility strongly correlate with presentation ratings. Increases in path co-visibility were correlated with increases in subjective rating for perceived salience of themes. The restriction of angular size produced no significant improvement in the analysis, probably

due to the small size of experiment settings. At the same time, the objective global co-visibility measure strongly correlates with the subjective path-based co-visibility measure. Increases in global co-visibility from the whole layout were correlated with increases in path-based co-visibility.

The results indicate that the layout of displays influences the perceived visual information during self-paced exploration in the exhibition and subsequently influence the rating for perceived salience of themes.

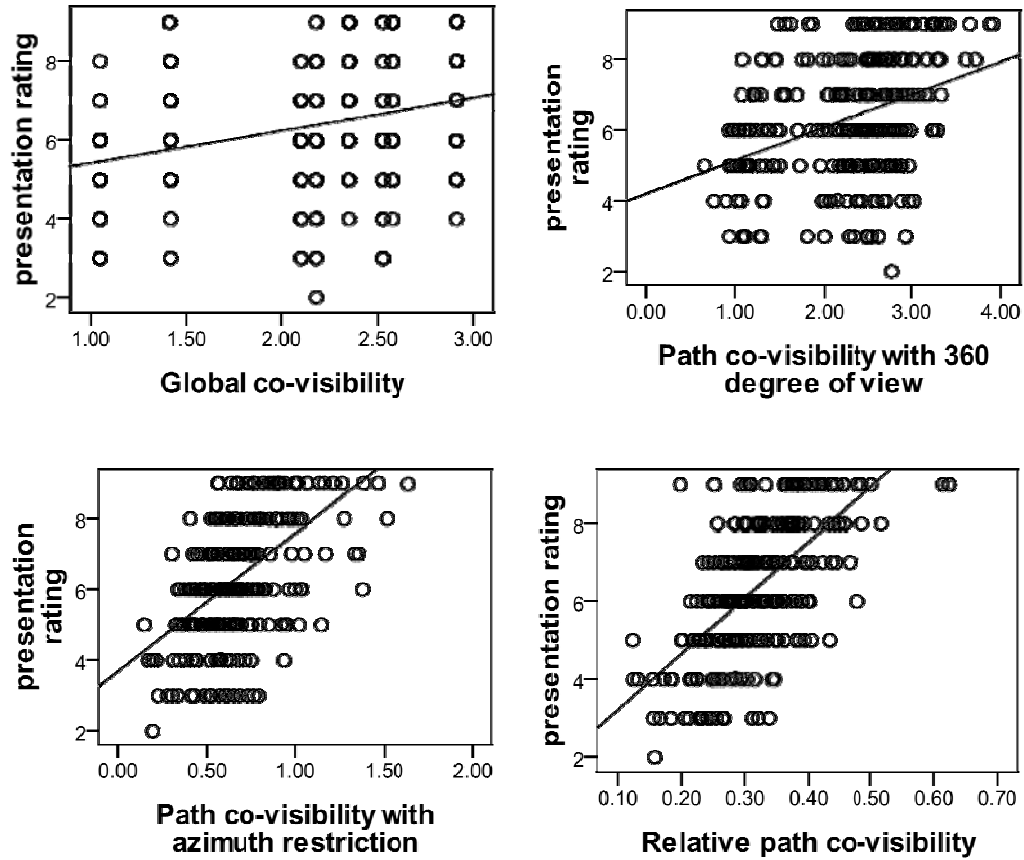


Figure 6.10: The correlations between ratings and co-visibility measures.

Top left: The presentation rating is positively correlated with the global co-visibility measures ($r=.272$, $p<.001$), which is computed as the average number of paintings in the theme that could be seen from all locations in the exhibitions.

Top right: The presentation rating is positively correlated with the path co-visibility with a 360-degree view ($r=.376$, $p<.001$). It is based on average number of paintings that could be seen from the individual path points with a 360-degree view.

Bottom left: The presentation rating is strongly positively correlated with the path co-visibility measures ($r=.536$, $p<.001$). It is based on average number of paintings that could be seen from the individual path points with the consideration of the orientation and field of view (100 degree) of the participants.

Bottom right: The presentation ratings for themes are also strongly positively correlated with the relative path co-visibility measures ($r=.536$, $p<.001$). It is the ratio of the total accumulated number of visible paintings of one theme to the total accumulated number of visible paintings of all themes with azimuth restriction from the whole path taken by the participant in the exhibition.

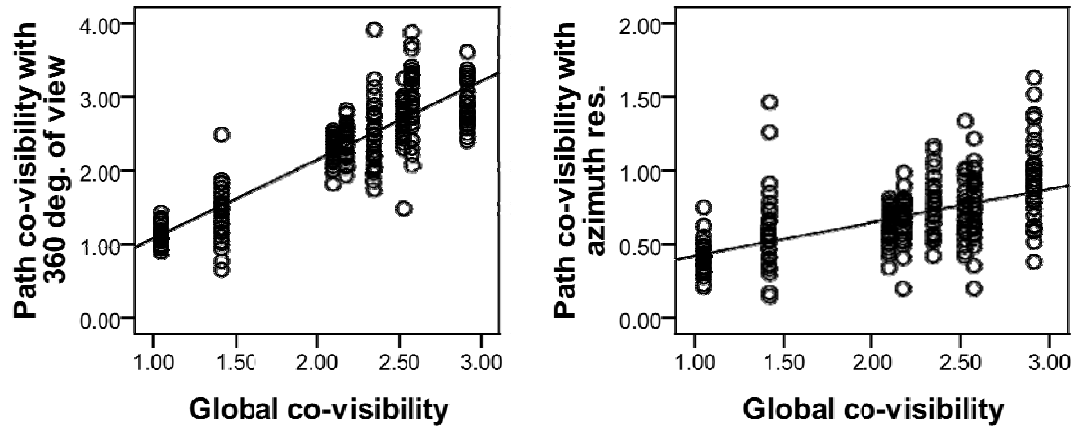


Figure 6.11: The correlations between co-visibility measures. The global co-visibility measure is strongly correlated with path co-visibility with a 360-degree view ($r=.884$, $p<.001$)(left figure), and path co-visibility with azimuth restriction ($r=.552$, $p<.001$)(right figure).

6.4.4 The comparison of visiting duration and path length in four layouts

The visiting duration and path length during initial exploration in four layouts were compared with paired t-tests (Figure 6.12).

The average visiting duration was 139, 111, 134, and 116 seconds in cellular, freestanding, overlapping and ring layouts respectively. There was a significant difference in the exploring time for the following four pairs: cellular ($M=139$, $SD=87$)-freestanding ($M=111$, $SD=71$); $t(34)= 3.13$, $p =.004$, cellular ($M=139$, $SD=87$)-ring ($M=116$, $SD=104$); $t(34)= 3.62$, $p =.001$, overlapping ($M=134$, $SD=78$)-freestanding ($M=111$, $SD=71$); $t(34)= 3.75$, $p =.001$, and overlapping ($M=134$, $SD=78$)-ring ($M=116$, $SD=104$); $t(34)= 3.08$, $p =.004$. The difference in the remaining pairs was not significant.

The average path length was 106, 85, 99 and 85 meters in cellular, freestanding, overlapping and ring layout respectively. There was a significant difference in the

visiting path length for the following two pairs, cellular ($M=106$, $SD=58$) –freestanding ($M=85$, $SD=33$); $t(34)= 2.66$, $p =.012$, overlapping ($M=99$, $SD=44$)- freestanding; $t(34)= 3.26$, $p =.003$. The difference in the remaining pairs was not significant.

In sum, during initial exploration, people spent significantly more time in the cellular and overlapping layout than that in freestanding and ring layout, and people walked significantly more distance in cellular and overlapping layout than in the freestanding layout.

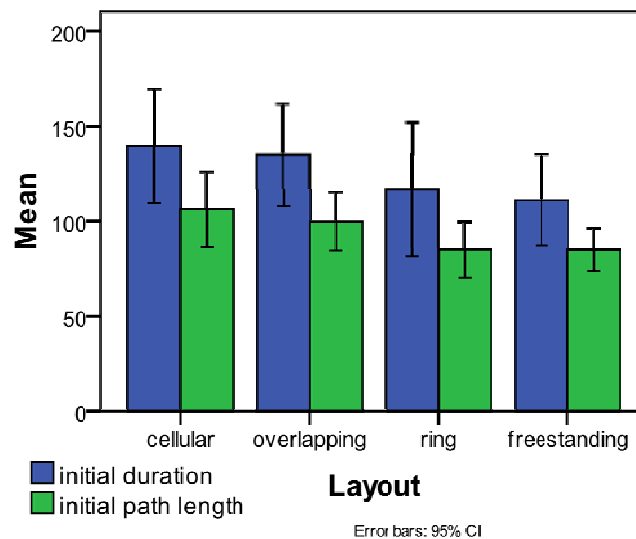


Figure 6.12: The visiting duration and path length during initial exploration in four layouts.

We also identified the shortest path to visiting all paintings once and returning to the starting location in each layout (Figure 6.13). Visiting a painting here means standing in the front of a painting at a distance maintaining a 60-degree viewing angle. The path length of the shortest path and the actual path taken by the participants during initial exploration were compared (Table 6.3). In each layout, the shortest path is shorter than

the paths taken by participants in the initial exploration. The path co-visibility of a 360-degree view for the shortest path and the actual path were also compared (Table 6.3). In each layout, the path co-visibility of the shortest path is less than that of actual paths.

The result shows that our participants take longer paths than the ideal shortest path. However the paths taken have a greater degree of co-visibility than the shortest path. This may be explained by the way the tasks are formulated. The participants are asked to attend to themes so they might arguably be choosing paths that lead to choices where greater numbers of paintings of a particular theme are visible.

Table 6.3: The path length and path co-visibility with a 360-degree view for the shortest path and the paths taken by the participants during initial exploration.

layout	length of the shortest path	length of actual path (mean)	co-visibility for the shortest path	co-visibility for actual path (mean)
cellular	69.50	106.28	3.88	3.97
freestanding	59.50	85.11	9.26	9.32
overlapping	57.80	99.91	7.89	8.04
ring	58.30	85.15	7.22	7.34

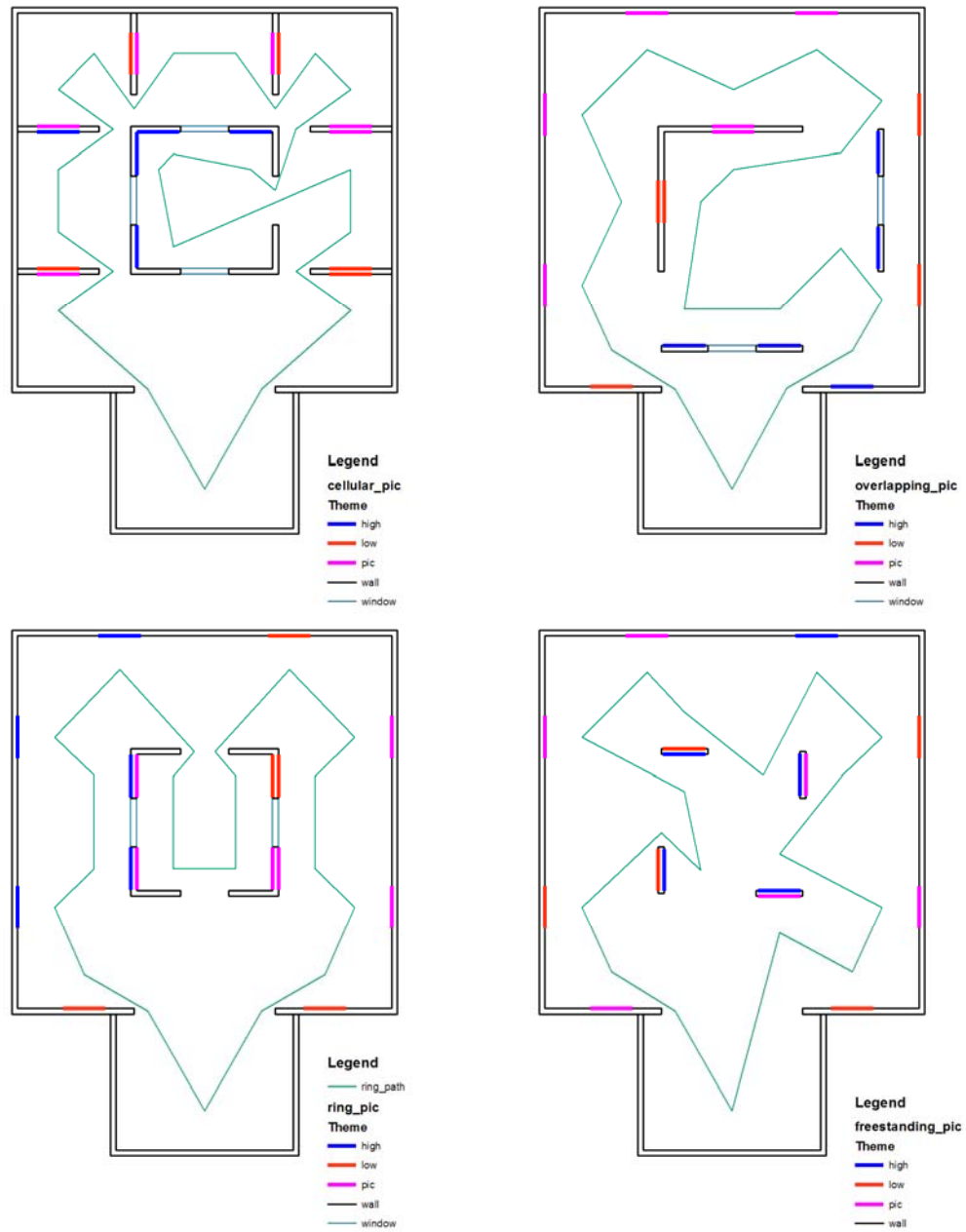


Figure 6.13: The shortest path to visit all paintings.
Visiting a painting means standing in the front of a painting at a distance maintaining 60 degree of viewing angle.

Cellular, overlapping, ring, and freestanding layouts have total partition wall lengths of 30.8m, 16.6m, 12.8m, 6.4m respectively (Figure 6.14). The average visiting duration and path length to explore each layout is perfectly rank-order correlated with the total length of partition wall in each layout (Spearman's correlation coefficient =1.0, $p<.001$). Thus, people tend to spend more time, and walk longer distances, in the layouts with longer partition walls.

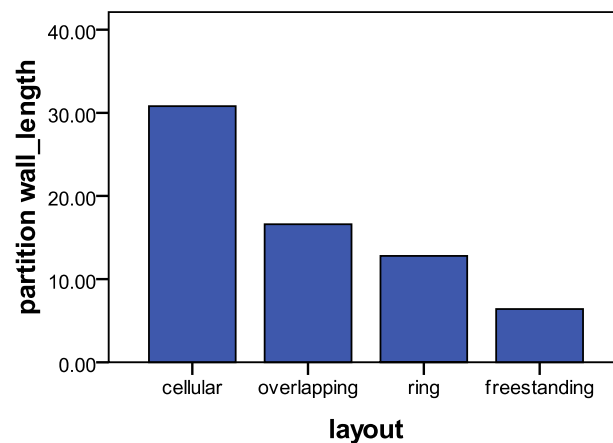


Figure 6.14: The total length of partition wall in cellular, overlapping, ring, and freestanding layouts. The average visiting duration and path length to explore each layout is perfectly rank-order correlated with the total length of partition wall in each layout (Spearman's correlation coefficient =1.0, $p<.001$).

6.4.5 The comparison of presentation ratings in four layouts

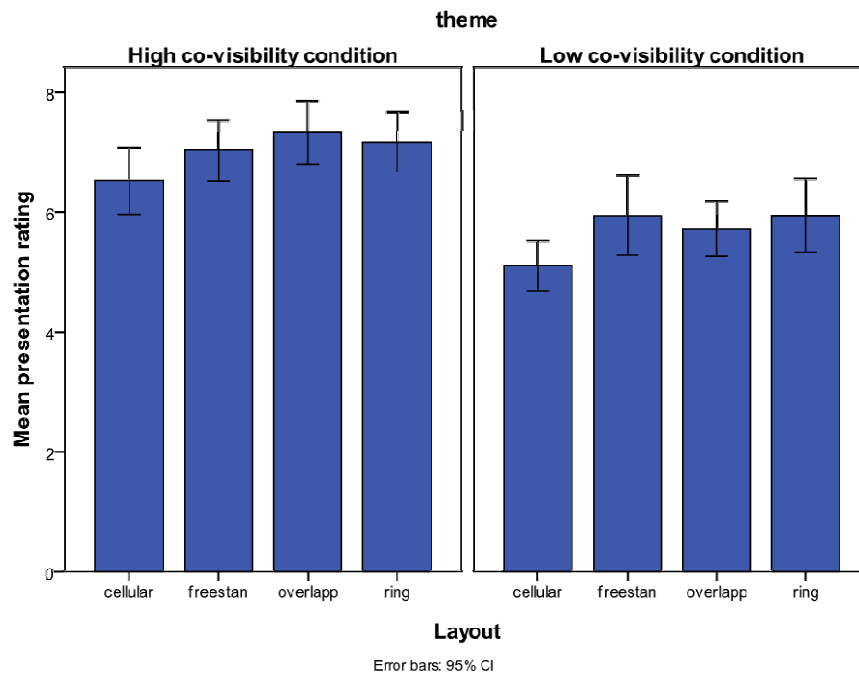


Figure 6.15: The presentation rating for theme in high and low co-visibility conditions in different layouts.

The average presentation ratings in four layouts were compared with paired t-test (Figure 6.15). For themes in the high co-visibility condition, there was a significant difference in the following two pairs: cellular ($M=6.45$, $SD=1.64$)–freestanding ($M=7.12$, $SD=1.59$); $t(41)=-2.49$, $p=.017$, and cellular ($M=6.45$, $SD=1.64$) –overlapping ($M=7.29$, $SD=1.71$); $t(41)=-2.28$, $p=.028$. The difference in the remaining pairs was not significant.

For themes in the low co-visibility condition, there was a significant difference in the following two pairs: cellular ($M=5.17$, $SD=1.43$) –freestanding ($M=6.02$, $SD=1.86$);

$t(41)=-2.26$, $p=.029$, cellular-overlapping ($M=5.81$, $SD=1.51$); $t(41)=-2.06$, $p=.046$. The difference in the remaining pairs was not significant.

The ratio of presentation rating for themes in the high co-visibility condition to rating for themes in the low co-visibility condition per subject was also compared across the four layouts with a paired t-test. There was not any significant difference in any pairs among the four layouts: cellular ($M=1.27$, $SD=.57$), freestanding ($M=1.33$, $SD=.61$), overlapping ($M=1.35$, $SD=.55$), and ring ($M=1.33$, $SD=.74$).

As discussed above, cellular, overlapping, ring, and freestanding layouts have total partition wall lengths of 30.8m, 16.6m, 12.8m, 6.4m respectively (Figure 6.14). The average presentation rating for the theme in the low co-visibility condition is perfectly rank-order correlated with the total length of partition wall in each layout (Spearman's correlation coefficient $=-1.00$, $p<.001$) (Figure 6.16). However, the average presentation rating for the theme in the high co-visibility condition is not significantly correlated with the total length of the partition wall (Spearman's correlation coefficient $=-.40$, $p=.60$). Nevertheless, the result should be interpreted with caution because only four data points were used in the test. A large sample size in future studies may lead to more definite findings.

In sum, the presentation ratings were significantly lower in the cellular layout than those in freestanding and overlapping layout for the theme in both the high co-visibility condition and the low co-visibility condition. Furthermore, the presentation rating for the theme in the low co-visibility condition was lower in the layout with longer partition walls. It seems the layout influences the presentation rating, especially for the theme in the low co-visibility condition. The strong influence of layout on the

presentation rating for the theme in the low co-visibility condition can be explained by the fact that member displays of the theme in the low co-visibility condition are relatively scattered across the layout. Thus co-visibility among them is strongly influenced by the partition walls in the layout. On the other hand, member displays of the theme in the high co-visibility condition are relatively concentrated in the layouts and thus less co-visibility among them is less influenced by the partition walls in the layout. From a designer's perspective, the results indicate that the open floor plan supports incidental and informal co-visibility among displays better than the traditional "closed" floor plan.

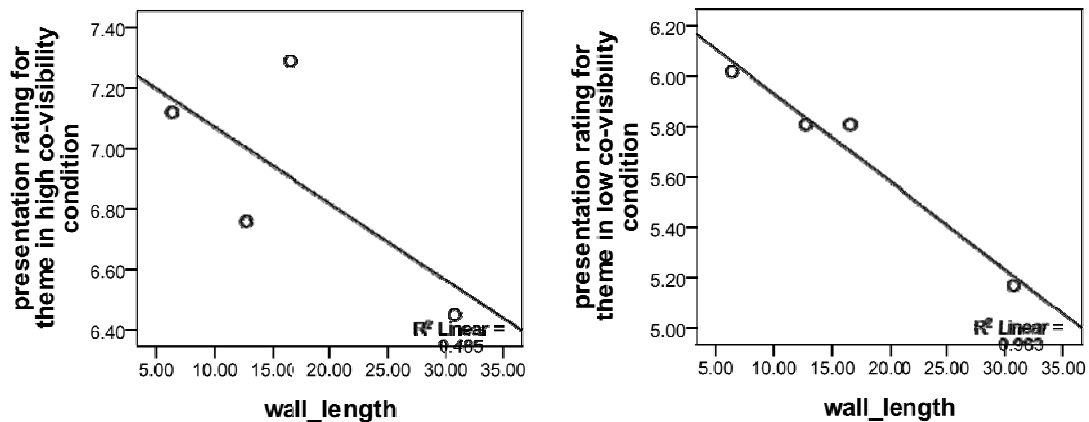


Figure 6.16: The correlation between average presentation rating and wall length. Left: The correlation between average presentation rating for theme in the high co-visibility condition with the total length of partition wall in each layout (Spearman's correlation coefficient = -.40, $p = .60$). Right: The correlation between the average presentation rating for theme in low co-visibility condition with the total length of partition wall in each layout (Spearman's correlation coefficient = -1.00, $p < .001$).

6.5 Discussion

In the present study, we investigated whether the clarity of presentation for conceptual themes of paintings varies as a function of the degree to which the set of paintings is co-visible from the layout or from the paths taken by participants. To sum up, our results reveal the following findings:

1) The self-reported clarity of presentation for conceptual themes is influenced by co-visibility conditions. Both the binomial test and paired-samples t-test show that people judge the theme in the high co-visibility condition as more clearly presented in the exhibition than that in the low co-visibility condition.

2) The clarity of presentation for a theme is correlated to the degree to which the set of objects is co-visible from all locations in the exhibition. It is more strongly correlated to the degree to which the set of objects is co-visible from the paths taken by the participants, particularly when azimuth restrictions are placed on the analysis, or when the co-visibility of member paintings of the theme takes into account co-visibility with non-member paintings.

3) The degree to which the set of objects is co-visible from the paths taken by the participants is correlated with the degree to which the set of objects is co-visible from all locations in the exhibition. In other words, the layout of displays strongly influenced subjective path-based co-visibility information.

4) The participants took longer paths than the ideal shortest path. However, these longer paths had a greater degree of co-visibility than the shortest path.

5) Our participants tended to spend more time and walk longer distances during initial exploration in the layout with longer partition walls when the number of displays is held constant.

6) Presentation rating for the theme in the low co-visibility condition was lower in the layout with longer partition walls. It seems the layout influences the presentation rating, especially that for the theme in the low co-visibility condition.

Overall, the results suggest that our notion of categorical salience partially depends on our experience of co-visibility of member objects in the category. There are two important implications of our results.

Firstly, many museum curators use the spatial layout of objects to express the ideas and relations between displayed objects. One commonly used technique is to make related objects in either same or different spaces co-visible. The multiple visual connections are supposed to express both the affinities and contrasts between the objects (Psarra, 2009). This study provides empirical evidence for the usefulness of this technique. It seems our participants can consciously or unconsciously notice the co-visible conditions among different paintings, and thus rate the clarity of presentation for a theme according to this particular spatial property. Nevertheless, questions remain whether co-visibility enhances differences as much as enhancing similarities.

Furthermore, different layouts are associated with different exploring duration and path length with the same set of displays. Our results tentatively indicate that the total length of partition walls is one of the factors that affects the duration of exploration. Museum curators thus can use layout as a way to prolong or shorten the exploration to enrich the observer's experience.

Moreover, the presentation rating for the theme in the low co-visibility condition was negatively correlated with the total length of partition walls in a layout. It seems that layout strongly influenced the presentation rating for the theme in the low co-visibility condition. If the total length of partition walls in a layout indicates the degree of openness of the layout, our results tentatively suggest that open floor plans better facilitates informal co-visibility among displays than more "closed" floor plans.

In sum, our results tentatively suggest that museum curators can use different spatial layout of displays to fine tune the visiting experience and cognitive impacts in exhibitions. However, a larger study is still needed to assess the effects of layout differences. The four layouts used in this study were so simple that we can only get indication of how different types of layout behave differently. More complex settings should be examined in the future to yield more concrete design recommendations for museum curators and designers.

Secondly, the clarity of presentation for a theme is more strongly correlated with co-visibility when it is measured from the path rather than from all locations. We believe the results of this study emphasize the importance of fuller and richer sensory-motor experiences. This study supports that coordinating multiple visual fields and movement affects the conceptualization of perceived salience in this study.

CHAPTER 7: FINDING LOCATIONS THAT MAXIMIZE CO-VISIBILITY

7.1 Introduction

Visibility towards important objects or building components in architectural space influences experience and behavior, such as wayfinding performances and open exploration patterns. For example, Braaksma and Cook (1980) revealed that the ratio of the number of available sight lines and the total number of possible sight lines among different locations in ten airports is correlated with the self-reported wayfinding difficulty by passengers. Locations with low visibility from other locations are reported to be more difficult to find than those with high visibility. Haq and Zimring (2003) reported people rely on the number of visible decision nodes (i.e., how many additional nodal corridor intersections could be seen from a given node) to navigate through three large hospitals during open-ended explorations of the premises. Most recently, Omer and Goldblatt (2007) reported that a high degree of co-visibility between an origin and a target landmark improves wayfinding performance in a simulated virtual town.

Peponis and his colleagues have demonstrated the effect of co-visibility of freestanding exhibits on visitor's engagement of individual exhibits in open-plan science exhibitions (Peponis, et al., 2004). They found that the recorded interaction between visitors and exhibits was associated with the number of other exhibits from which each exhibit was visible. For the interactive science exhibits under investigation, this was measured manually by imagining a subject standing in front of each exhibit as if to

engage its interactive interface and counting how many interactive interfaces of other exhibits were visible.

The results from Chapter 5 also suggest that nurses, consciously or unconsciously, are attuned to visibility towards patients in the intensive care unit. On the other hand, the physicians are attuned towards the generic visibility that maximizes the overall area of view fields.

Recently, Franz & Wiener (2008) asked the participants to find the positions that maximized and minimized the visible area for 16 simulated indoor scenes. The accurate performance of the participants demonstrated that one particular property of visual fields, namely area of the isovist, registers explicitly when people explored those virtual simulated environments.

7.2 Method

The present study investigates whether subjects are able to accurately compare the power of visual fields, not from the point of view of generic visibility, but from the point of view of directed visibility aimed at a particular family of objects on display.

The present study employs the same virtual environments used in the previous chapter to test whether participants would select locations with maximum visibility towards a given set of paintings. Participants actively explored four simulated exhibitions of M.S. Escher's works. Each exhibition located a pair of conceptual themes in either high or low co-visibility conditions. After participants exited the self-paced exploration, they were asked to answer several questions and were prompted with names of themes.

Then they were instructed to return to the exhibition and find a location from which the greatest number of paintings belonging to each theme can be seen.

The locations of those photographs will be compared with the optimized locations based on the co-visibility measures developed by the author. It is hypothesized that those photograph locations can be predicted by the objective co-visibility measures. In other words, proportionally more photograph locations should be predicted by location with maximum visibility towards a given set of paintings.

The photograph task was applied here for the following reasons. 1) It can test whether people can compare the power of visual fields from the point of view of directed visibility aimed at a particular family of objects on display. 2) It can also capture people's understanding of whole spatial configuration by identifying the optimized photograph locations. 3) Finally, the spatial pattern of photograph locations can be easily graphically represented and thus visually examined.

7.2.1 Participants

Thirty-six students from Georgia Institute of Technology participated in this experiment, with approximately equal numbers of men (19) and women (17) represented in the sample.

7.2.2 Materials

The same materials as those used in the previous chapter.

7.2.3 Design and procedure

The experimental design was introduced in the previous chapter. The detailed photograph procedure follows.

After participants explored the exhibition and answered questions, they were asked to revisit the exhibition and find a location from which the greatest number of paintings belonging to each theme can be seen. They were instructed to take at least one photograph for each theme in a high co-visibility condition and one photograph for each theme in a low co-visibility condition. However, if they changed their mind during the task, they could take a second photograph for each theme. Thus, they could not take more than two photographs per theme and four photographs in total. The permission to take a second photograph was offered to allow at least one correction.

The photograph locations were recorded by the computer program. In only 16 out of all 142 trials did participants take the opportunity to capture two photographs for one theme. The second photographs are always as good, or considerably better, than the first based on the criterion used when asking for the photographs. In 9 out of those 16 trials, the second photograph captured more paintings belonging to the theme than the first. In the remaining 7 trials, the second photograph captures the same numbers of paintings belonging to the theme as the first. Thus, if a participant took two photographs for one theme, only the second photograph was used in subsequent analysis.



Figure 7.1: Sample photographs taken by participants to capture maximum number of paintings belonging to the same theme.

7.3 Data analysis and results

7.3.1 Density of photograph locations

The data analysis method is similar to that in chapter 5. The unit of measure is the number of paintings belonging to one theme that are visible from any given location.

With the script I developed, co-visibility (or directed visibility in the terminology of the previous chapters) could be calculated and represented graphically for all layouts, from all occupiable locations on the tessellation. For the theme in the high co-visibility condition, the value consistently ranged from a minimum of 0 to a maximum of 5. By contrast, for themes in low co-visibility conditions, the range of the co-visibility measure is not consistent across the four layouts. For example, the value ranges from 0 to 4 in overlapping and ring layouts, 0 to 5 in freestanding layouts, 0 to 2 in cellular layouts. Thus, we only analyze the photograph locations for themes in high co-visibility conditions for the co-visibility value has a similar range in four layouts (Figure 7.2-Figure 7.5).

The new measure introduced here is the co-visibility variable with field of view restriction. Given the participants have a consistent field of view of 100 degree in the experiment, the maximum number of paintings belonging to one theme that are visible in this field of view was calculated. The value is always equal to or less than the unrestricted co-visibility value for the exact same location. For the cellular, ring, and overlapping layouts, the value consistently ranges from 0 to 5. However, for the freestanding layout the value ranges from 0 to 4.

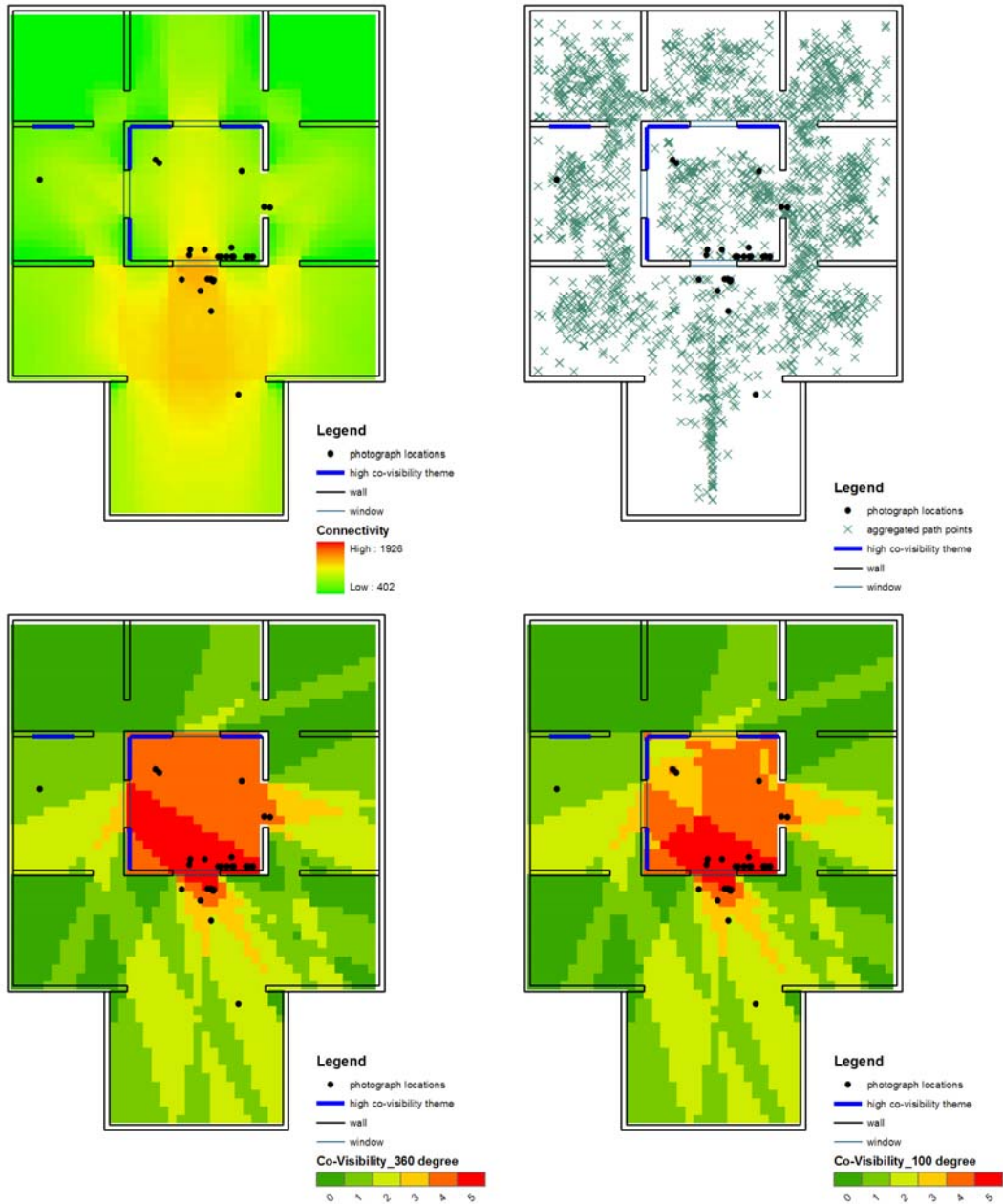


Figure 7.2: The visibility graphs of the cellular layout. Top left: The area of the generic visibility polygon. Top right: The positions occupied by all subjects during the initial exploration. Bottom left: the co-visibility variable with a 360-degree view. Bottom right: the co-visibility variable with field of view restricted to 100 degrees—that is the maximum number of paintings belonging to the same theme that are visible in 100-degree field of view.

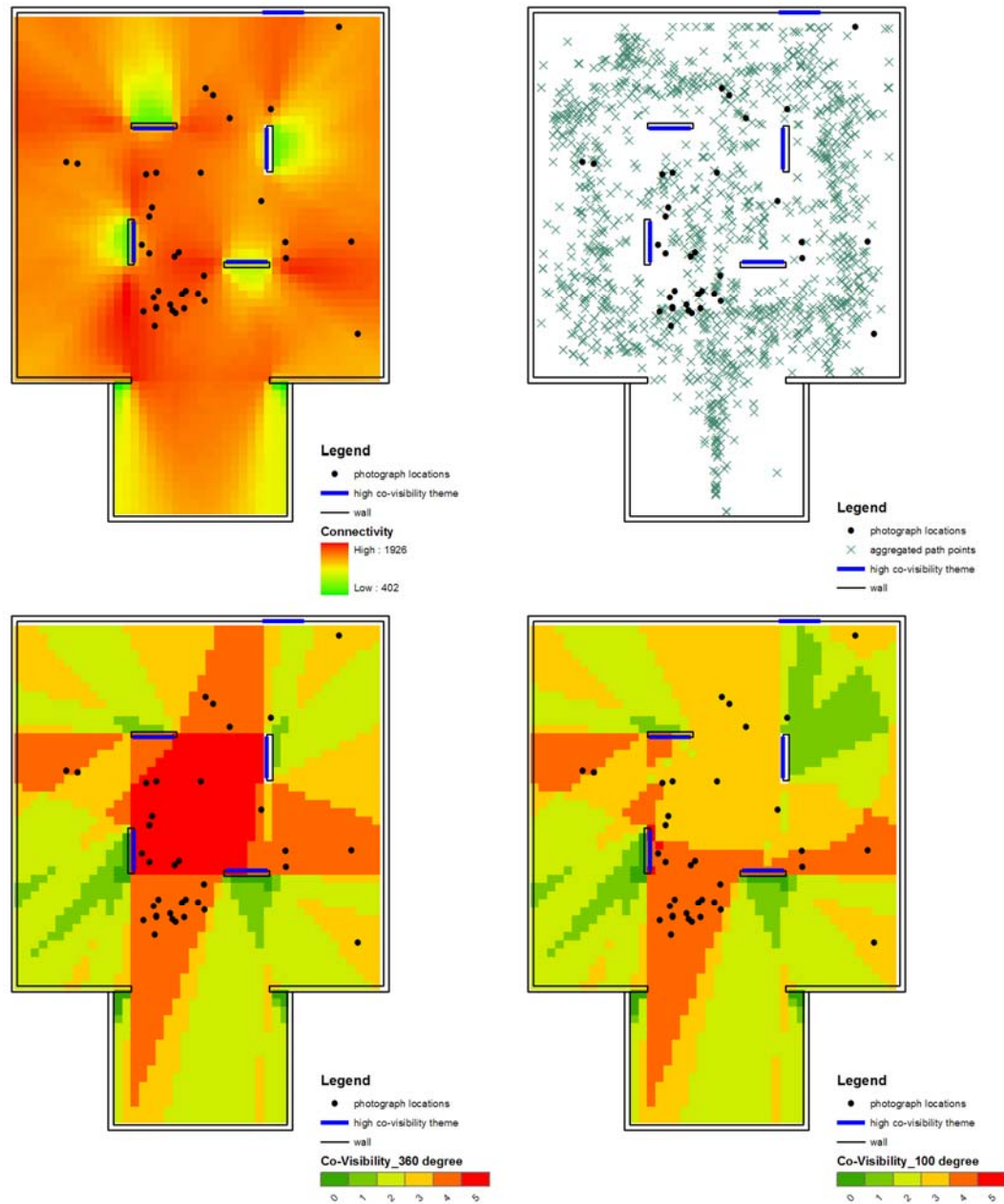


Figure 7.3: The visibility graphs of the freestanding layout. Top left: The area of the generic visibility polygon. Top right: The positions occupied by all subjects during the initial exploration. Bottom left: the co-visibility variable with a 360-degree view. Bottom right: the co-visibility variable with field of view restricted to 100 degrees—that is the maximum number of paintings belonging to the same theme that are visible in 100-degree field of view.

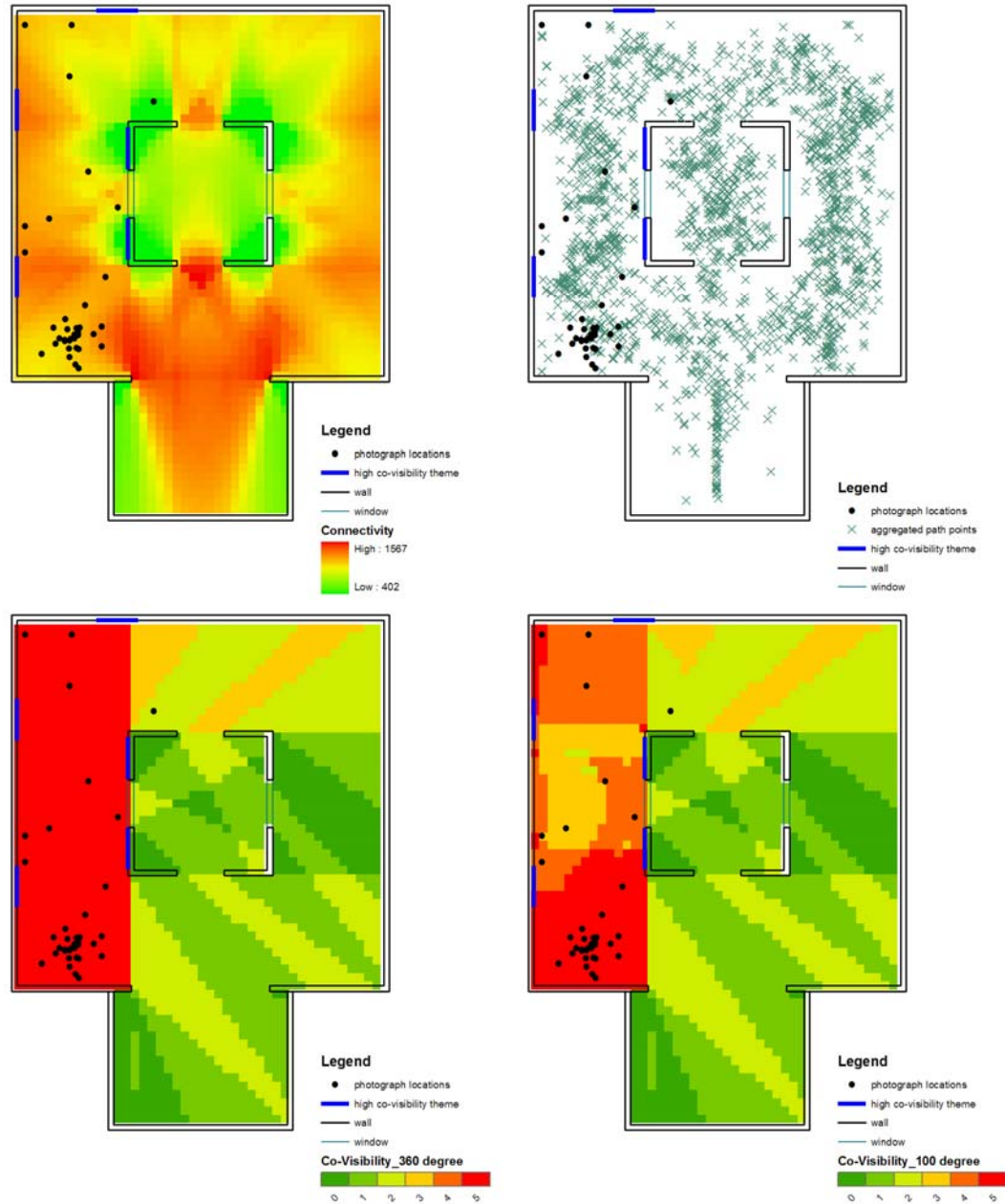


Figure 7.4: The visibility graphs of the ring layout. Top left: The area of the generic visibility polygon. Top right: The positions occupied by all subjects during the initial exploration. Bottom left: the co-visibility variable with a 360-degree view. Bottom right: the co-visibility variable with field of view restricted to 100 degrees—that is the maximum number of paintings belonging to the same theme that are visible in 100-degree field of view.

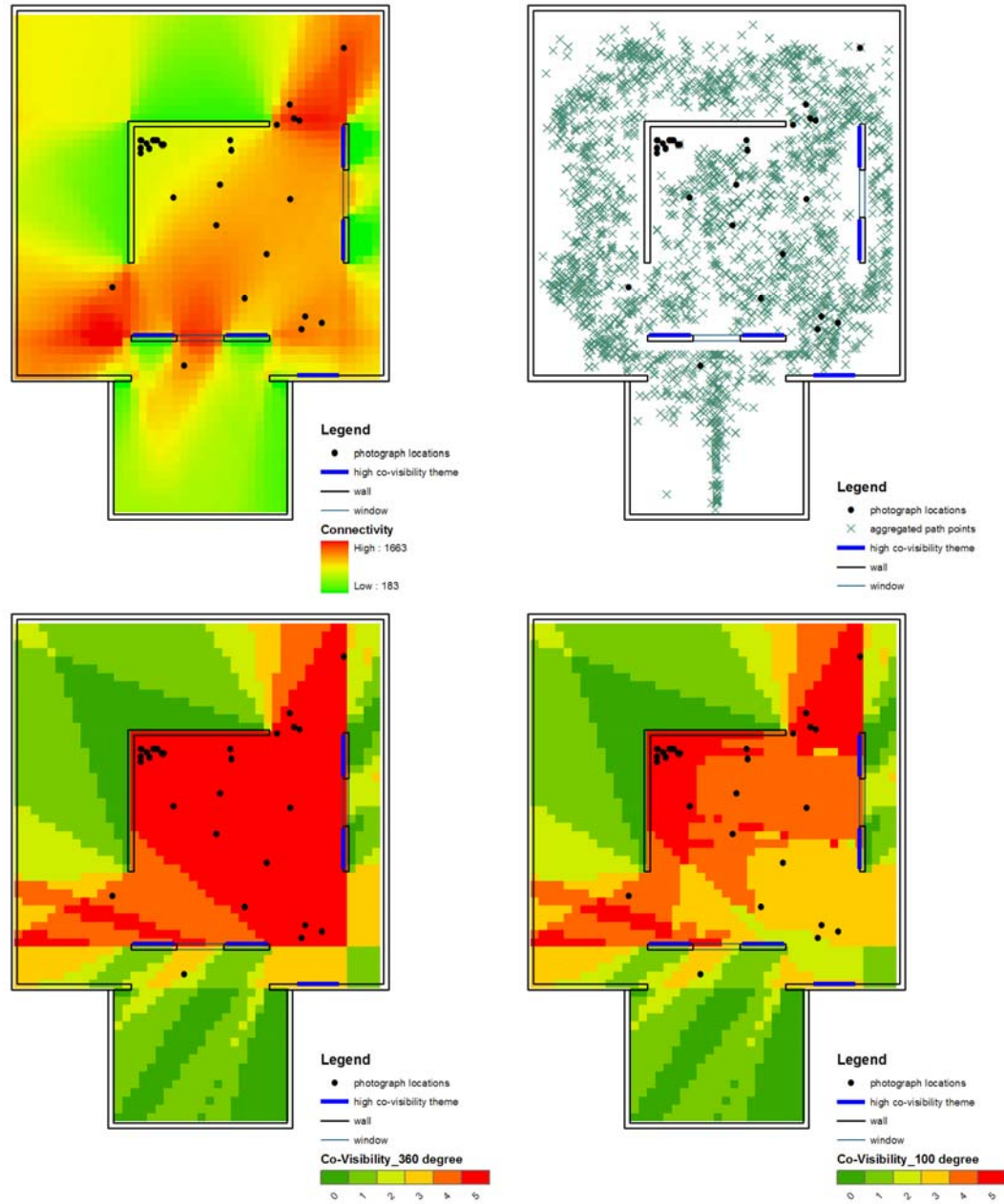


Figure 7.5: The visibility graphs of the overlapping layout. Top left: The area of the generic visibility polygon. Top right: The positions occupied by all subjects during the initial exploration. Bottom left: the co-visibility variable with a 360-degree view. Bottom right: the co-visibility variable with field of view restricted to 100 degrees—that is the maximum number of paintings belonging to the same theme that are visible in 100-degree field of view.

The number of photograph locations selected by the participants per relevant co-visibility region of the plan was treated as the dependent variable. This was adjusted by dividing the number of selected photograph locations at each level of co-visibility value by the corresponding number of unit tiles at that level. By computing the density of photograph locations, rather than absolute photograph location frequencies per co-visibility zone, the data was normalized for the uneven area of the various co-visibility zones. The following figures show the number of points and photograph locations at each level of co-visibility value across the four layouts (Figure 7.6).

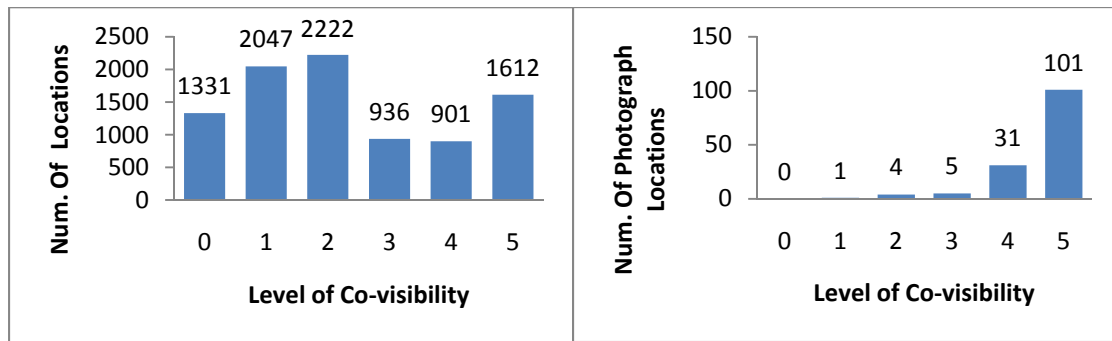


Figure 7.6: The distribution of photograph locations and co-visibility value. Left: the number of points at each level of co-visibility value. Right: the number of photograph locations presented at each level of targeted visual connectivity value.

Generic visual connectivity was also computed for the purpose of comparison, using the standard output of Depthmap. Generic visual connectivity measures the number of tiles that are visible from each location on the tessellation; it is roughly equivalent to the area of the isovist.

In order to study how generic visual connectivity impacts behavior as compared to co-visibility, and given that there are only 6 co-visibility values, the generic visual connectivity was divided into 6 levels with equal intervals, and recoded into an ordinal variable which ranges from 1-6 for each layout. The following figures show the number of points and photograph locations at each level of recoded generic visual connectivity value across all trials (Figure 7.7).

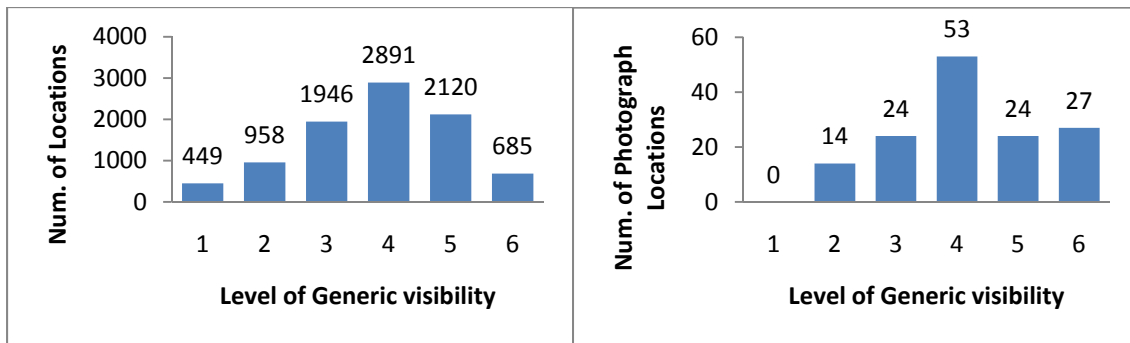


Figure 7.7: The distribution of photograph locations and generic visibility value. The left figure shows the number of points at each level of generic visual connectivity value, which is broken into 6 levels with equal intervals. The right figure shows the number of photograph locations presented at each level of generic visual connectivity value.

Chi-square goodness of fit test was used here. The null hypothesis is that people will choose randomly and thus photograph locations will be distributed between the co-visibility zones in proportion to the area covered by each zone.

For co-visibility, the proportional distribution of photograph locations in co-visibility zones significantly differs from the proportional distribution of the area covered by each zone, $\chi^2(5, N = 142) = 327, p < .001$. For generic visibility, the proportional

distribution of photograph locations in generic visibility zones also significantly differs from the proportional distribution of the area covered by each zone, $\chi^2(5, N = 142) = 34$, $p < .001$.

The results show the photograph locations were not randomly chosen. More specifically there is a bias towards selecting locations on the maximum co-visibility zone.

Considering co-visibility without restrictions (Figure 7.6): 101 out 142 (71.1%) photograph locations have the maximum co-visibility value of five. Thus, the majority of photograph locations fall in the zones with the top level of co-visibility value.

Considering co-visibility with field of view restriction, 100 out 142 (70.4%) of photograph locations have the maximum refined co-visibility value (a value of five for cellular, ring and overlapping layout and a value of four for the freestanding layout).

Considering generic visibility, only 27 (19.0%) photograph locations are in the top level of generic visibility.

For the top level of co-visibility, co-visibility with field of view restriction, and generic visibility value, the density of photograph location was .062, .097, .039 respectively. Thus, the density of photograph locations is much stronger in the top level of co-visibility value than for generic visibility values. The density is also stronger in the top level of co-visibility with field of view restriction than for unrestricted co-visibility. In other words, the photograph locations are better predicted by the locations with high co-visibility value, restricted or unrestricted, than by those with a high generic visibility value.

7.3.2 Photograph performance and path length and visiting time

The link between the performance of photograph and time and path length taken by the participants during the both initial exploration and revisiting is examined here.

The performance of photographs is based upon the co-visibility value with field of view restriction. It is coded as binomial variable; with the value 1 representing the photograph locations having the maximum possible co-visibility value (i.e., a value of five for cellular, ring and overlapping layouts and a value of four for the freestanding layout), with the value 0 representing all other photograph locations. According to this criterion, 100 out of 142 photograph locations were grouped in the high photograph performance and the remaining 42 were grouped in the low photograph performance.

The independent t-test was used to compare the exploration time and path length during both initial exploration and revisit for two groups of photographs: those with high or low performance (Figure 7.8).

During initial exploration, there was a significant difference in the path duration for groups with high photograph performance ($M=110$, $SD=8.3$) and low photograph performance ($M=160$, $SD=12.8$); $t(140)= 3.244$, $p <.001$. There was also a significant difference in the path length for groups with high photograph performance ($M=87.9$, $SD=4.5$) and low photograph performance ($M=108.3$, $SD=7.0$); $t(140)= 2.449$, $p =.015$ (Figure 7.8).

During revisiting, there was not a significant difference in the path length and duration for groups with high photograph performance and low photograph performance.

The result suggests that the participants with high photograph performance spent less time and walked less distance during the initial exploration than those with low

photograph performance. The finding contradicts our intuition, that people who spent more time, or saw more views would have developed better knowledge. The result can be explained by the argument that people with poor spatial abilities or poor navigation skills tend to spend more time in the initial exploration and also tend to have low photograph performance. While people with better spatial ability or navigation skill need less time to understanding the physical environment and also performed better in photograph tasks.

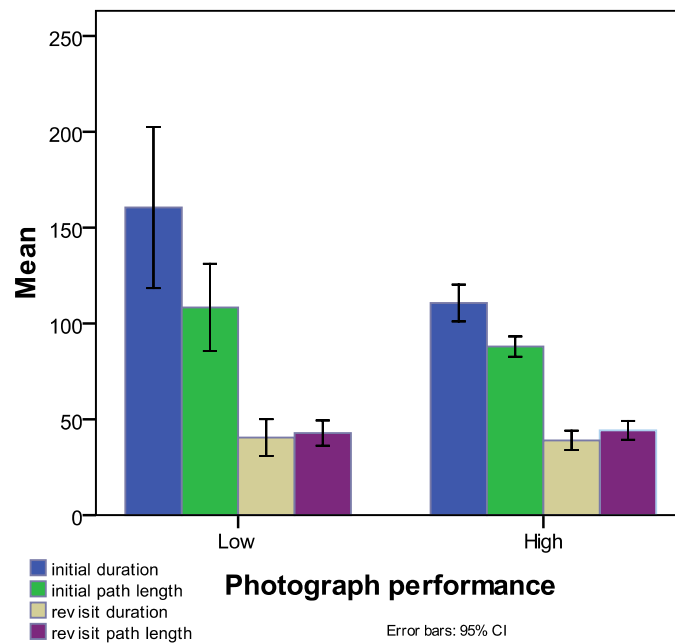


Figure 7.8: Relationship of photograph performance and walking distance and time. People achieving high photograph performance spent less time and walked less distance during the initial exploration than those with low photograph performance. During the revisit, there was not a significant difference in path length and duration for groups with high photograph performance and low photograph performance.

7.3.3 The comparison of photograph performance in four layouts

It is also interesting to compare the differences in the photograph performance in the four layouts. In each layout, the ratio of number of photographs having the maximum level of co-visibility value with field of view restriction and total number of photographs were computed. The ring layout has the highest ratio of 77.8%, while the overlapping layout has the lowest ratio of 65.7%. The cellular and freestanding layout has ratios of 68.6%, and 69.4% respectively.

More interestingly, high performance in the photograph task indicates that co-visibility works effectively in all four layouts. The results show that it works well in the situation where all displays are located in the same space (or convex space), as in ring layout. It also works well in the situation where displays are located across layers (not the same convex space) as in the cellular and freestanding layouts. For example, in the cellular layout, the majority of photographs were taken with the effect to include the painting outside the central space. This is also the case for the freestanding layout. In sum, it seems that people take consideration of co-visibility both in the same space and across layers.

The order of the ratio of high photograph performance does not align with the rank of ratio of number of tile locations with top co-visibility level and total number of tile locations. The ratio can be better explained by the spatial pattern of top level of co-visibility with field of view restriction in the layout (Figure 7.2-Figure 7.5). In the ring layout, the locations with the top level of co-visibility are positioned near the circulation core, thus those locations can be easily discovered by the participants in the exploration.

In the overlapping layout, the locations with top level of co-visibility are positioned in the enclosed corner between two long partitions in the center. Thus these locations are far away from the circulation core and are relatively unlikely to be encountered by natural movement in the exploration.

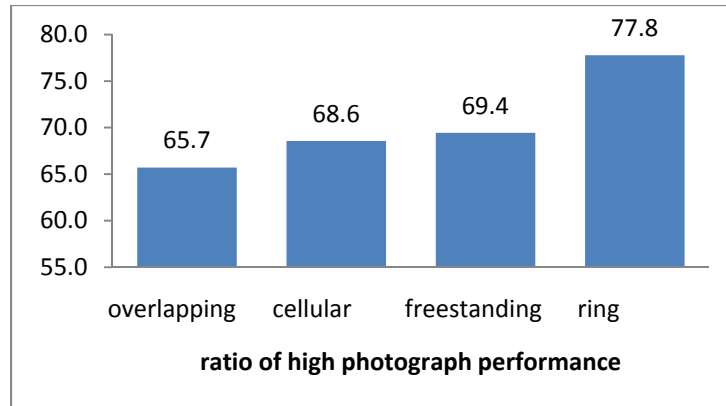


Figure 7.9: The ratio of number of photographs having the maximum level of co-visibility value with field of view restriction and total number of photographs. The ring layout has the highest ratio of 77.8%, while the overlapping layout has the lowest ratio of 65.7%.

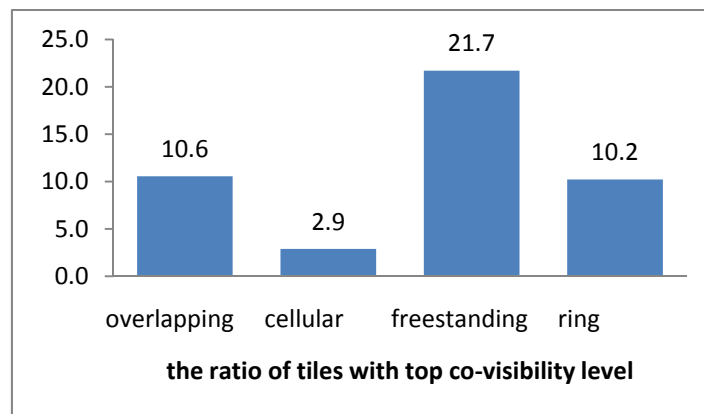


Figure 7.10: The ratio of the number of locations having the maximum level of co-visibility value with field of view restriction and total number of locations. The freestanding layout has the highest ratio of 21.7%, while the cellular layout has the lowest ratio of 2.9%.

7.4 Discussion

In the present study, we investigated whether the participants can find the locations that maximize visibility towards a set of paintings belonging to the same theme in the simulated exhibitions. In other words, we tested if the participants can direct their attention to a set of objects in spaces upon request. To sum up, our results reveal the following findings:

1) The density of photograph locations is much stronger at the top level of co-visibility value than at the generic visibility value. The density is also stronger in the top level of co-visibility with field of view restriction than without field of view restriction.

2) The participants with high photograph performance (meaning the photograph locations having the maximum co-visibility value) spent less time and walked less distance during the initial exploration than those with low photograph performance.

3) Our participants seemed to take consideration of co-visibility both in the same space and across layers (in different convex spaces) during the photograph task.

4) This study also demonstrated that the photographing task is a useful research method. It can reflect people's understanding of both layout of the space and spatial layout of the displays.

There are two important implications of our results.

Firstly, this study provides evidence that people take consideration of co-visibility both among displays in the same space and across layers in an exhibition. Thus, museum curators should take note that co-visibility can be used to effectively express affinities and contrasts between displays in the same space and as well as across.

Secondly, the results suggest that proportionally more photograph locations can be expected in the areas with higher visibility towards paintings belonging to the same theme. Our participants showed very good performance in finding the spatial locations that maximized visibility towards selected objects in space. By the same token, the directed visibility analysis predicted the spatial behavior better than the generic visibility.

As we discussed in the Chapter 5, people with different roles are tuned towards different visibility information in the same setting. For example, nurses are more tuned to directed visibility towards their patients, especially when interacting with others. Physicians are more tuned to generic visibility. They tend to locate themselves where they can see a larger area, which gives them a better awareness of the surrounding environment and on-going situation.

In a similar pattern, people with different goals tunes to different visual information in the built environment. Previous research suggests that people can perceive the structure of generic visibility as well (Franz & Wiener, 2008). The results of this experiment support the notion that people can perceive the structure of view fields towards selected objects in spaces.

Taken together, these studies suggest that people can flexibly direct their attention to different objects or features in the built environment. Cognitive flexibility may be explained in the ecological psychology by Gibson (1979). Because there are infinite pieces of visual information in the environment, Gibson suggests that the information about affordances that an environment provides (i.e., what the environment offers, provides, or furnishes for either good or ill) can be picked up directly. More interestingly, the relationship between humans and the environment is reciprocally defined by

affordances. They are the functionally significant properties of the environment with regard to a particular group of people who share common roles, tasks, or demographic background. Therefore, the visual information of environments that is related to tasks, goals or jobs, may be perceived directly by a set of users in the environment. Thus, we suggest that visibility analysis should focus on different sets of visual features in an environment that are closely related to different sets of users.

CHAPTER 8: CONCLUSION

This is a study of the spatial affordances of buildings that allow them to organize and transmit cultural ideas and to support the performance of organizational roles. The particular affordances under consideration are those that arise from the manner in which buildings structure the visual fields that are potentially available to a situated observer. Previous studies have shown that patterns of communication in offices, patterns of viewing and learning in exhibition spaces, patterns of everyday life in restrictive environments and patterns of wayfinding in hospitals are all systematically affected by the structure of visual fields. This study shows that the impact of spatial organization becomes clearer when we draw a distinction between generic visibility patterns and directed visibility patterns.

In studying generic visibility patterns we are considering all parts of a setting that are visible from each occupiable location. In studying directed visibility patterns we focus on a previously specified set of visual targets and ask how many become visible from each occupiable location. Parametric restrictions concerning the direction into which a subject faces and the viewing angle sustained by the target object are also taken into consideration. The aim is to demonstrate how such refinements of visibility analysis, supported by the development of appropriate analytical tools, lead to more precise and penetrating insights as to how building users tune their behavior to the spatial affordances of environment, and how the environment impacts their understanding in turn. Three different studies were presented. The first used directed visibility measures in order to evaluate the affordances of different nursing-unit designs relative to how well nurses are

able to survey patients in different rooms as they go about their duties. The second study focuses on the manner in which nurses and physicians position themselves in a neurological ICU, particularly when interacting. The third study investigates how aware exhibition visitors become of the visual structure of environment and how the visibility structure of exhibitions affects the ability of visitors to conceptually group paintings according to their thematic content.

8.1 Major findings

Case study 1: The layout of three nursing units was evaluated according to a directed visibility index, based on the proportion of beds that are visible from each location. This spatial evaluation of the three nursing units is well aligned with previous empirical findings (Trites, et al., 1970) regarding the length of paths that nurses are required to walk during their shift as well as the quality of cooperation between them. By considering the results of visibility evaluation in conjunction with the published evaluation of nurses' work it is inferred that higher directed visibility indexes are associated with more efficient work performance, specifically with the reduction of distances walked by nurses in their performance of their duties, and with enhanced opportunities of contact and communication between nurses. Thus, the first study points to the usefulness of directed visibility analysis in the evaluation of work environments in which visual surveillance plays a significant role. This is not a surprising finding, but it sets the stage for the second case study which looks more thoroughly at the manner in which the behavior of actors in a medical environment is tuned to spatial structure.

Case study 2: Based on the systematic recording of medical staff positions in a neural ICU, it was shown that nurses position themselves so as to take advantage of higher directed visibility values relative to patients' beds, particularly when interacting. Physicians, on the other hand, position themselves so as to take advantage of generic visibility. The results indicate people with different roles are tuned to different features of environment. The finding is important because it suggests that the visual structure of environment is cognitively recognized, tacitly if not consciously. Furthermore, the reading the affordances of environment relative to work-role becomes manifest through the spatial mapping of behavior.

The third study addresses a different building type in order to further examine the cognitive recognition of the spatial affordances in the environment and its impacts.

Case study 3a: Forty-two subjects each navigated four small virtual exhibition environments. Their responses indicate that the perceived clarity of presentation of a given theme represented by four paintings is associated with the extent to which the member paintings are co-visible; the association is stronger when co-visibility is analyzed based on the path followed by each subject, subjected to azimuth restrictions and measured taking into account the ratio of co-visible theme-member paintings and paintings belonging to other themes. Co-visibility, however, does not influence the judgment as to whether a theme is clearly expressed in the member paintings. In other words, spatial arrangement influences whether a theme is likely to be recognized based on its presentation, but not whether the member paintings are thought to express it clearly once it has been recognized.

Case study 3b: The forty two subjects were asked to take pictures so as to show as many member paintings of a theme as possible as clearly as possible in a return visit to the virtual environments. It was shown that subjects were well able to identify the locations which are objectively best suited for the task. Surprisingly, subjects that identified the best locations more precisely had usually followed shorter paths in their first visit to the exhibition. Thus, spatial judgment, as indicated by the choice of photograph viewing points, is associated with spatial ability, as indicated by the length of path necessary to comprehend a small exhibition visited for the first time.

8.2 Conclusions

Overall, this study leads to three important conclusions.

1) From theoretical perspective, the understanding of how the spatial affordances of environment support the performance of roles or the understanding of displays provides a foundation for developing architectural design aims and architectural design proposals. As people interact with the spatial affordances of environment, they tacitly learn to take systematic advantage of them, so that the performance of roles is linked to consistent spatial distributions of behavior. Roles, in other words acquires a measureable spatial signature. Furthermore, as people explore visual information, they are able to judge how well content-based themes are supported by patterns of co-visibility of theme members. Thus, theme and spatial arrangement become intertwined. The refinement of visibility analysis is a key step to demonstrate the effect of spatial affordances. At the same time, the methodologies and questions developed in this study can help situate buildings and building use as interesting subjects of study within the larger field of

cognition, and within the field of embodied cognition more particularly. As suggested in the earlier chapters, there is a lack of studies that look at the built environment as part of a cognitive cycle whereby cognitive assumptions drive design and objective spatial affordances support subsequent cognitive performance and associated behavior.

2) Important design applications follow, especially for museum curators. Case study 3b provides evidence that people are sensitive to patterns of co-visibility among displays, not only in the same space but also across boundaries and layers of spatial depth. Pending further analysis, this implies that exhibition layouts based on sequences of clearly bounded rooms are not the only way to group displays so as to encourage their interpretation as members of themes. Furthermore, different layouts are associated with different exploration duration and path length with the same set of displays. Our results tentatively indicate that the total length of partition walls is one factor. Museum curators thus can use layout as a way to prolong or shorten the exploration and to enrich the observer's experience. However, as will be discussed below, more work is needed in order to precisely understand the way in which the arrangement of boundaries should be aimed to affording appropriate patterns of co-visibility and the way in which the addition or extension of boundaries might encourage a slower pace of movement through the exhibition.

3) From a methodological point of view, we can enhance the applicability of visibility analysis to studies of the behavioral impacts of spatial properties by drawing a distinction between generic visibility patterns and directed visibility patterns. Directed visibility combines aspects of both spatial structure and the structure of program in the visibility analysis. Its quantitative measures have meaningful interpretations related to

particular people, roles and settings. It can enhance the applicability of visibility analysis to studies of the behavioral and cognitive impacts of spatial properties, as shown in case study 1.

This study also provides the analytic innovation that synthesizes directed visibility patterns from the viewpoint of movement. It is a preliminary but useful way to objectively describe sensory-motor experiences. This innovation encourages further exploration of relationships between mental presentations of abstract concepts and sensory-motor experiences, or other related topics.

Furthermore, this study demonstrates the usefulness of photographing task as a technique for the following reasons. 1) It can test whether people can explicitly compare the power of visual fields towards a set of objects on display. 2) It can also capture people's understanding of whole spatial configuration by identifying the optimized photograph locations. 3) The spatial pattern of photograph locations can easily be graphically represented and thus visually examined.

8.3 Limitations and future work

Some limitations of this study and recommendations for future research follow.

1) The first limitation concerns the method of analysis of environments. Even the refined visibility analysis presented in this thesis still relies on the 2-dimensional (2D) horizontal floorplan, as is the case with previous visibility analyses in architecture (Batty, 2001; Benedikt, 1979; Turner, et al., 2001). True 3D geometry is not supported in the analysis yet. The viewshed analysis of a landscape field in GIS is usually based on a 2.5D raster surface, and every planar location can only have one piece of height information.

Such analysis usually comes up against problems in representing 3D geometry, such as buildings. The future development of visibility analysis should integrate true 3D environments. In this manner, it will become possible to study the effect of low partitions or wall apertures at varying heights above the floor.

2) The second limitation of this study concerns the simplicity of the exhibition environments studied. Quite possibly, the study of more complex environments might lead to more definite results of how the organization of space mediates the generic effects of the structure of visibility on the perception and understanding of exhibits. While this study indicated that more highly subdivided layouts are associated with greater difficulty in perceiving themes, no conclusions could be reached regarding other differences, for example between a layout using small free standing partitions and a layout situating a room inside a room. In short, this study is a preliminary step towards the longer term goal of understanding how generic principle interacts with design choice and design solution-type.

3) In this study, displays were selected and arranged for purely experimental purposes, while attempting to equalize all properties (such as the spacing between paintings, viewing height and dimensions of paintings) in such a way as to foreground differences in theme co-visibility only. In the future, virtual environments could be used in order to study exhibition arrangements that are implemented with actual collections and with specific curatorial intentions in mind. One way to do this would be to reconstruct in a virtual environment actual exhibitions in actual buildings, particularly when curatorial intentions are documented. In this manner, the extension of the methodologies deployed in the present study would serve to develop evaluations of actual

settings and exhibitions in the short term, and of exhibition design principles in the longer term.

4) The fourth limitation of the study arises from the manner in which the cognitive registration of the spatial affordances of environment was inferred. In the case of the study of the effects of the spatial affordances of environment upon the behaviors of nurses, for example, further progress can be made by correlating affordances with work outcomes, or with objectively measurable psychological states of the actors: do nurses perform better when they can interact while keeping an eye over their patients? Do nurses feel less anxious when they do not have to choose between maintaining eye-contact with patients and learning from or seeking assistance from other nurses? In the case of the effects of spatial affordances upon the understanding of displays, further progress can be made by developing more refined methods to study how co-visibility supports comparisons between displays. The theme evaluation exercises used here (regarding presentation or expression) are only a first step in this direction.

5) Perhaps the most immediate extension of this study needs to address the manner in which directed visibility and co-visibility patterns are affected by the systematic variation of the underlying topology as well as the exact geometry of designs. In the case of the four exhibition settings, alternative generative principles were used to place different layouts within the same boundary. As discussed, the differences in generative principles were expressed as differences in the length of internal walls, the structure of circulation and the resulting patterns of visibility and potential co-visibility. More work is needed to understand the impact of varying metric properties while holding

the generative principle constant, or by holding metric properties constant (for example constant internal wall length) and trying to work with alternative generative principles.

Along similar lines, the three wards compared in chapter 4 have almost the same number of beds but different areas. Further work is needed to decide if differences of generative principle can be accommodated while keeping area constant. Further work is also needed in order to test the effect of small variations in layout once the generative principle is decided, for example by varying the boundary of a nurses' station in a radial layout or by varying the extent to which a nurses' station has overviews of circulation in a corridor-based layout.

The aim of the extension of the work envisaged here can be simply described as follows: having established the significance of patterns of visibility, co-visibility and directed visibility from the point of view of their cognitive and behavioral impacts, this study sets the ground for asking: how are these patterns affected by major design decisions (generative design principles) and by the subsequent elaboration of designs (metric adjustments)? Answering these questions will help bridge the gap between research aimed at understanding how settings work to provide visual affordances and the application of research to design.

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